Essays on macroeconomic stabilization policy in small open economies

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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text.

The first case study "Stabilization bias for a small open economy: The case of New Zealand" has been accepted for publication by the *Journal of Macroeconomics*. The second case study is a summary of joint work with Timothy Kam (ANU) and Kirdan Lees (RBNZ) published as "Uncovering the hit-list for small inflation targeters: a Bayesian structural analysis" in the *Journal of Money, Credit and Banking*, volume 41, issue 4, p583-618. The third case "The Role of International Shocks in Australia's Business Cycle", has been accepted for publication by the *Economic Record*. The fourth case study is based on joint work with Haroon Mumtaz at the Bank of England.

The views expressed in this thesis are those of the author only, and do not necessarily reflect the institutions that the author is currently or previous affiliated with.

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Summing up my Ph.D. experience at the ANU: *"It is not the gold that's important, it is the journey ... "*

Executive Summary

Broadly speaking, macroeconomic stabilization policy entails the design and implementation of fiscal and/or monetary instruments in such a way as to ensure macroeconomic outcomes converge to their targeted levels within some reasonable time period. Whether this can be achieved depends on many factors, including the structure of the economy, the nature of underlying disturbances, the set of objectives, the effectiveness in policy implementation and the appropriateness of the instruments. Keynes' (1936) *General Theory* explained how fiscal and monetary policy can be used to end depressions. Over time, many have viewed this as an argument for stabilization policy itself – Keynesian economics. While the literature has largely focused on the closed economy setting, this thesis aims to provide a deeper understanding of the role of monetary policy as a stabilization tool in a small open economy.

This thesis includes four case studies. The first study looks at the importance of time-inconsistent policy for New Zealand and how this notion has led to a number of interesting insights regarding the central bank's behavior and institutional design. The results indicate that the size of the stabilization bias is nearly twice as large for a small open economy (SOE) relative to that usually found for closed economies. The results also indicate that the size of the stabilization bias is increasing with the policymaker's preference for stabilizing exchange rate fluctuations.

The second case study tries to uncover the underlying macroeconomic stabilization objectives for Australia, Canada and New Zealand, and to see how this can be used to enhance the transparency and accountability in the implementation of monetary policy. The estimated policy preference parameters suggest the three central banks are very similar in their overall objective. None show a concern for stabilizing the real exchange rate and all three share a concern for minimizing the volatility in the change in the nominal interest rate.

The third case study examines the sources of business cycle fluctuations, in particular, the role of international shocks for Australia. In contrast to previous VAR studies, international factors are found to contribute to over half of the output forecast errors whereas demand shocks have relatively modest effects.

The fourth case study examines possible changes to the international transmission mechanism in the case of U.K over the period 1975 to 2005. In the period before 1990 the response of the domestic economy resembles a classic beggar-thy neighbor scenario, with increases in foreign money supply resulting in a fall in U.K. real activity. Whereas, for the period after 1990, the results suggest a foreign monetary policy easing has substantially different effects on the U.K. In this later period, the response is positive but insignificant.

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CHAPTER 1

INTRODUCTION

1.1 Research question

BROADLY SPEAKING, macroeconomic stabilization policy entails the design and implementation of fiscal and/or monetary instruments in such a way as to ensure macroeconomic outcomes converge to their targeted levels within some reasonable time period. Whether this can be achieved depends on many factors, including the structure of the economy, the nature of underlying disturbances, the set of objectives, the effectiveness of policy implementation and the appropriateness of the instruments. Keynes' (1936) *General Theory* explained how fiscal and monetary policy can be used to end depressions. Over time, many have viewed this as an argument for stabilization policy itself – Keynesian economics. This thesis primarily focuses on the role and uses of monetary policy as a stabilization tool in a small open economy (SOE).

The Keynesian's view has not been without scrutiny in the literature. Friedman (1962) in his book *Capitalism and Freedom* argued that active countercyclical policy cannot affect the average level of unemployment and output. Lucas and Sargent (1979) went further, contending that it is not only impossible to increase the average level of output, it is also impossible to stabilize it. More recently, Lucas (1987, 2003) has argued that even if stabilization policies are effective, they would yield negligible welfare gains and hence it should not be a macroeconomic priority.

Lucas's conclusion has failed to influence the practice. Policies focusing on output and price stability have long been explicit or implicit objectives of monetary policy in many industrialized countries. Increasingly, the approach is being adopted by developing and emerging market economies.

At the end of the 1970's, inflation had risen to very high levels across most industrial countries. In contrast, today most of these countries have inflation around or close to the 2 percent level with relatively low volatility. A result many would argue as being consistent with price stability. One concern might be that the low and stable levels of inflation may have been achieved at the expense of higher output volatility, but this has not been the case. Since the mid-1980's, the volatility of output and inflation has declined substantially across OECD countries, a phenomenon known as the "great moderation". In addition, the level and persistence of inflation has stayed around historical lows. Many studies have documented reduced-form evidence in support of this observation. For example Kim and Nelson (1999), McConnell and Perez-Quiros (2000), Blanchard and Simon (2001), and Cogley and Sargent (2005) in the case of the U.S., Benati (2006) for the U.K, and Summers (2005) for major industrialized countries. However, the issue related to the causes and consequences of these changes have been more controversial.

A large literature has examined changes to the monetary transmission mechanism during the great moderation, and conclusions are mixed. Cogley and Sargent (2002), and Clarida et al. (2000) lend support towards the hypothesis that changes in the U.S. macroeconomic dynamics were linked to changes in macroeconomic stabilization policies, "good policy". On the other hand, Primiceri (2005), Sims and Zha (2006), and Gambetti et al. (2008) are more sympathetic to the idea that it is the absence of adverse non-policy shocks that contributed to the great moderation "good luck".

The current global financial crisis has ignited the great moderation debate and the role of monetary policy in stabilizing the business cycle. Arguably, the recent events point to more evidence in favor of the good luck hypothesis. Many may even argue that the unusually low world-wide interest rates at the beginning of this decade may have contributed to the excessive credit expansion that proceeded the crisis. This is an interesting and important area of research that will no doubt dominate the macroeconomic research agenda for years to come. It is important to stress that this thesis primarily focuses on the role of monetary policy in stabilizing the business cycle, it does not try to address the relative importance of good policy versus lower macroeconomic disturbances in explaining the great moderation.

While the literature has largely focused on the closed economy setting, this thesis provides a deeper understanding on the role of monetary policy as a stabilization tool for small open economies. International trade and financial market integration induce additional constraints for the SOE's stabilization problem. First, the inter-dependence with the rest of world can alter the fundamental tradeoffs among the various objectives (or target variables). Second, there can be additional policy objectives beyond output and inflation stability, for example, exchange rate stability. Third, foreign disturbances may be completely outside the control of domestic stabilization policy instruments.

This thesis focuses on these very issues. Chapter (3) looks at the importance of time-inconsistent policy for New Zealand and how this notion has led to a number of interesting insights regarding the central bank's behavior and institutional design. Chapter (4) uncovers the underlying macroeconomic stabilization objectives for three of the earliest inflation targeters: Australia, Canada and New Zealand. In particular, the role of exchange rate stabilization in the policy makers' objective function. Chapter (5) examines the sources of Australia's business cycle fluctuations focusing on the role of international shocks. Chapter (6) investigates changes to the international transmission mechanism of foreign disturbances for the U.K from 1975 to 2005.

The empirical analysis presented in this thesis is primarily focused on four SOEs – Australia, Canada, New Zealand and U.K. Although, the methodologies developed here can be easily related or applied to other SOEs.

1.2 Methods of investigation

The analysis contained in this thesis relies heavily on the use of structural and empirical macroeconomic models. Earlier policy oriented models developed in the 1960s, such as the MIT-Penn-SSRC model used by the Federal Reserve, were based on long-run tradeoffs between unemployment and inflation. It was not until the 1970s that the concept of accelerationist Phillips curve was formally introduced, but expectational elements were still largely missing. The next generation of macro models incorporated the importance of expectations in the determination of real activity and inflation (Bryant et al., 1993, provide an excellent overview of these earlier models). Since then, these models have become workhorse models for policy analysis in central banks and government institutions around the world.[1]

More recently, the focus has shifted towards building models with stronger micro-foundations. This approach builds on two recent developments in the literatures, namely

[1] Examples are the QPM model at the Bank of Canada by Coletti et al. (1996), and the FPS model at the Reserve Bank of New Zealand (RBNZ) by Black et al. (1997a).

real business cycle models and New Keynesian theory. These models emphasize the concepts of optimizing representative agents and the role of nominal rigidities. They are often referred to as dynamic stochastic general equilibrium (DSGE) models. Subsequently, a large literature has surfaced with the aim of bringing these models closer to the data (see Smets and Wouters, 2003; Ireland, 2004; Rabanal and Rubio-Ramírez, 2005; Lubik and Schorfheide, 2007, for example).

This thesis makes extensive use of new open economy models with a slight preference for smaller and more tractable model structure. There are several advantages in adopting this approach. First, rich micro-foundations embedded in DSGE models make the policy conclusions more robust to the Lucas Critique. Second, advances in econometric knowledge has allowed for a more efficient parameterization of the model with respect to the historical data. Third, it enhances the ability to perform various counter-factual analysis. Lastly, these models explicitly incorporate assumptions about future expectations and how they are formed.

However, DSGE models are often described as too "rigid" when taken to the data. In addition to DSGE models, part of the analysis is based on more flexible econometric techniques such as vector autoregression (VAR) and factor-augmented VAR models to uncover the sources business cycle fluctuations and the international transmission of shocks.

1.3 Summary of key results

Chapter (3) uses a fully specified DSGE model to explore the relationship between a central bank's policy objectives and the size of the stabilization bias. The model is estimated using data from New Zealand. The results indicate that the size of the stabilization bias is nearly twice as large for a small open economy (SOE) relative to that usually found for closed economies. The results also indicate that the size of the stabilization bias is increasing with the policymaker's preference for stabilizing exchange rate fluctuations.

Chapter (4) estimates the underlying structural macroeconomic stabilization objectives of three of the earliest explicit inflation targeters within the context of a SOE DSGE model. The central banks are assumed to set policy optimally and the policy objectives are reverse engineered from observed time series data. Joint tests of the policy preference parameters suggest that central banks are very similar in their overall objective. None of the central banks show a concern for stabilizing the real exchange rate. All three central banks share a concern for minimizing the volatility in the change in the nominal interest rate. It also shows that the resulting optimal policy rule responds to exchange rate movements, even in the case where the central banks do not explicitly care about exchange rate stabilization. This result is also corroborated by results from an alternative simple-rule characterization and estimation of central bank behavior. These last two findings point to the pitfalls of making inferences, from the level of ad-hoc simple rules, about what central banks may care about.

Chapter (5) examines the sources of Australia's business cycle fluctuations. The cyclical component of GDP is extracted using the Beveridge-Nelson decomposition and a structural VAR model is identified using robust sign restrictions derived from a structural small open economy model. In contrast to previous VAR studies, international factors are found to contribute to over half of the output forecast errors whereas demand shocks have relatively modest effects.

Finally, chapter (6) extends the open economy FAVAR models with time-varying coefficients and stochastic volatility to examine possible changes to the transmission of foreign money supply, demand and supply shocks to the U.K. The proposed model captures the changing co-movements among the macroeconomic time series by allowing their dependence on common factors to evolve over time. It also allows for stochastic volatility in the innovation process of the factors. The main results are as follows: A foreign monetary policy easing has substantially different effects on the U.K. in the period after 1990. In particular, the response of the domestic economy in the period before 1990 resembles a classic beggar-thy-neighbor scenario, with increases in foreign money supply resulting in a fall in U.K. real activity. In the later period, the response was positive but insignificant. Our estimates attribute this to a fall in exchange rate pass-through to relative prices. A foreign aggregate demand shock had a large positive impact on U.K. GDP during the years 1980-1990, but its impact in the more recent period has been substantially smaller. Foreign supply shocks were important for U.K. inflation during the 1970s and the persistence of the inflation response has also been smaller since the early 1980s.

1.4 Thesis structure

Each of the subsequent chapters in the thesis is self-contained and is organized as follows. Chapter (2) introduces the notion of stabilization policy, and discusses the recent developments in the area of open economy macroeconomic models and how these have been used in the policy process. It identifies remaining issues in the current literature and discusses how this thesis contributes to the ongoing debate. Chapter (3) investigates the size of the stabilization bias using New Zealand as a case study to explain why most SOE's choose to adopt inflation targeting. Chapter (4) estimates the macroeconomic objectives, and their relative tradeoffs, for Australia, Canada and New Zealand. Chapter (5) examines the sources of business cycle fluctuations focusing on the role of international shocks for Australia. Chapter (6) uses an open economy FAVAR model with time-varying coefficients and stochastic volatility to examine changes to the international transmission mechanism of international shocks for the U.K. Chapter (7) concludes on the main findings and offers suggestions for future work in this area.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

SINCE THE early 1990's, many countries have adopted inflation targeting as their formal framework for monetary policy. The regime is usually characterized by: (1) an explicit and publicly announced inflation target, either in terms of an interval or a point target; (2) a high degree of transparency and accountability; and (3) a relatively high degree of operational independence.

These central banks formulate policy in a forward looking manner and construct conditional inflation forecasts as an intermediate target to guide policy settings. In the process, they rely heavily on large-scale macroeconomic models, for example the Quarterly Project Model (QPM) model at the Bank of Canada by Coletti et al. (1996), the Forecast Projection System (FPS) model at the Reserve Bank of New Zealand by Black et al. (1997a), and the Bank of England Quarterly Model (BEQM) at the Bank of England by Harrison et al. (2005). On the other hand, statistical models such as vector autoregression (VAR) models are heavily used to help gauge the quantitative impact of various structural disturbances on the macroeconomy.

This chapter provides an overview of recent developments in the area of open economy macroeconomic models and how these have been used in the policy process. Section (2.2) discusses the objectives of macroeconomic stabilization policy and a brief overview of the current institutional framework for a few selected small open economies. Section (2.3) reviews the recent developments in structural open economy modeling and estimation techniques are discussed in section (2.4). Section (2.5) looks at an alternative approach in using VAR models. Section (2.6) concludes.

2.2 Macroeconomic stabilization policy

Macroeconomic stabilization policy can be broadly summarized as methods to mitigate short-run business cycle fluctuations around some long-run growth path using different policy instruments. Two policy tools are often emphasized in the literature: fiscal policy – the way that governments choose aggregate expenditure and tax collection; and monetary policy – the way central banks change the amount of money supply via the price of money – interest rates. Both of these are very powerful tools at the disposal of policymakers. This thesis will primarily focus on the study of monetary policy for small open economies.

The motivation behind the need for stabilization policy is simple. A risk averse agent would prefer a deterministic consumption path relative to a risky one with the same mean. Therefore, appropriate stabilization policy set up to help smooth an agent's consumption path can be viewed as welfare improving. To illustrate this, consider the following simple stylized example set out in Lucas's 2003 AEA Presidential address. Assuming a single consumer is endowed with the following stochastic consumption stream:

$$c_t = Ae^{\mu t}e^{-\frac{1}{2}\sigma^2}\epsilon_t \tag{2.1}$$

where μ is the deterministic growth rate of consumption, and $\log(\epsilon_t)$ is normally distributed with mean of 0 and variance σ^2. The mean consumption level at time t is, $E(c_t) = \bar{c}_t = Ae^{\mu t}$. The agent's lifetime utility function of current and future consumption path is assumed to be:

$$E\sum_{t=0}^{\infty}\left(\beta^t\frac{c_t^{1-\gamma}}{1-\gamma}\right) \tag{2.2}$$

where β is the discount factor and γ is the coefficient of risk aversion. One can measure the difference in lifetime utility for the risk averse agent between the stochastic consumption path of c_t and the deterministic path $\bar{c}_t$ such that:

$$E\sum_{t=0}^{\infty}\left(\beta^t\frac{((1+\lambda)c_t)^{1-\gamma}}{1-\gamma}\right) = \sum_{t=0}^{\infty}\left(\beta^t\frac{\bar{c}_t^{\,1-\gamma}}{1-\gamma}\right) \tag{2.3}$$

where λ represents the welfare gain from eliminating consumption risk. Taking logs, canceling and collecting terms gives:

$$\lambda \cong \frac{1}{2}\gamma\sigma^2 \tag{2.4}$$

This compensation parameter depends on the degree of risk aversion, γ, and the amount of volatility that is present, σ^2. One can think that σ^2 comprises two parts: a "non-removable" component that is purely exogenous and a "removable" component that depends on the structure of the economy and its transmission mechanism. Stabilization policy does not aim to eliminate all the volatility associated with consumption. However, appropriate stabilization policy can alter the way shocks are transmitted through the economy to help reduce the volatility of consumption. There are debates to exactly how much of the volatility can be attenuated. Lucas (1987, 2003) argues this may in fact be very small, yielding negligible improvements in welfare. However, Akerlof and Yellen (2004), and Barlevy (2005) provide alternative estimates and evidence to suggest Lucas's conclusion maybe misleading.

2.2.1 Objectives of monetary policy

In the last two decades, many central banks have begun concentrating on price stability and inflation control as their main policy objective. A number of central banks have formally adopted inflation targeting as the framework for the operation and implementation of monetary policy. Moreover, many countries recognize the importance of time-inconsistent policy following the work of Kydland and Prescott (1977), and Barro and Gordon (1983), and have subsequently changed their institutional framework to reflect this. These changes emphasize the importance of implementing monetary policy in a credible, accountable and transparent manner.

2.2.1.1 Time-inconsistent policy

Considered as one of the key developments in macroeconomics (Chari and Kehoe, 2006), Lucas (1976) famously argued that preferences and technology are invariant to policy, but private agents' behavior are not – the Lucas critique. In most cases, agents' current decisions depend on their expectations of what future policies will be, and policy makers must take those expectations into account when formulating current and future policy.

Consider the following simple example. At the beginning of the period, wage setters choose the nominal wage followed by the monetary authority choosing the rate of inflation. If inflation is higher than what wage setters expected, the real wage will fall inducing firms to demand more labour, and output is higher than its natural rate. Once wages are set, there is a great deal of incentive for the monetary authority to choose a higher inflation rate and therefore higher output. Without commitment, the monetary authority's claim to keep inflation low is time inconsistent and not credible. Agents will take this into account when setting wages, the result will be higher inflation than optimal and output remaining at its natural level – this is known as the discretionary *inflation bias.*

This insight has shifted much of the focus from the operational side of monetary policy to the design of institutional frameworks aimed at mitigating the time inconsistency problem. Rogoff (1985) proposed delegating the role of setting inflation to an independent authority to solve the inflation bias problem. Since then, the study of commitment and discretionary monetary policy has been extended from the static framework to incorporate realistic persistence in output and inflation. This requires monetary policy to be conducted in a forward looking manner with substantial effects on the equilibria. Svensson (1997) demonstrates discretionary policy can lead to a *stabilization bias* meaning that inflation volatility is too high, and output volatility is too low relative to the commitment equilibrium.[1] The size of the stabilization bias represents the degree of inefficiency in the economy due to implementing monetary policy in a time inconsistent manner. Chapter (3) evaluates the size of the stabilization bias for New Zealand and illuminates on why many SOEs choose to adopt inflation targeting.

2.2.1.2 Inflation targeting

Many countries have changed their institutional framework in apparent recognition of the time inconsistency problem. Three important institutional changes are especially evident in practice. First, central banks have become substantially more independent from political authorities in their decision making and their operation. Second, central banks have placed a lot more emphasis on price stability as their primary policy objective. Third, central banks have adopted a more transparent strategy for communicating the context and rationale of policy choices to the public. For many countries, these institutional changes are explicitly reflected in the legislative framework.

By 2002, 22 countries had formally adopted inflation targeting as their monetary policy framework (Truman, 2003).[2] These countries are all SOEs, ranging from developed economies to emerging market economies and the numbers are expected to grow over time.

[1]The stabilization bias differs from the inflation bias in the sense that it still occurs even when the monetary authority targets the natural level of output.

[2]The countries, listed by the date in which inflation targeting was adopted are as follows (and in some cases readopted): 1989, New Zealand; 1990, Chile; 1991, Canada and Israel; 1992, the United Kingdom; 1993, Australia, Finland, and Sweden; 1995, Spain and Mexico; 1997, Czech Republic and Israel (again); 1998, Poland and Korea; 1999, Brazil, Chile (again), and Colombia; 2000, Thailand and South Africa; 2001, Hungary, Iceland, and Norway; 2002, Peru and the Philippines.

They all openly publish their inflation target and most of them have a great deal of operational independence from the government. Furthermore, many central banks that have not formally adopted the framework, for example the US Federal Reserve, have been influenced by the approach one way or the other.

The framework, referred to as *constrained discretion* by Bernanke (2003), tries to strike the right balance between strict policy rules and pure policy discretion. Under such a framework, the central bank's primary focus would be inflation. However, given inflation and future inflation expectations are under control, policy makers can still stabilize output (and its other policy objectives) in the face of short-run disturbances. One may argue that, it would be easier for the central bank to maintain its other policy objectives when inflation expectations are better anchored.

Figure (2.1) displays the inflation experience for four SOEs that have adopted inflation targeting: Australia, Canada, New Zealand and the U.K.[3] The four panels of Figure (2.1) show the rate of inflation before and after the implementation of inflation targeting marked by a vertical line. Across the four countries, inflation fell substantially in all the countries following the adoption of the inflation target. Researchers continue to debate whether this decline was solely due to the change in policy. However, there is consensus that inflation targeting played a crucial role in the decline.

In practice, inflation targeting often involves setting bands of acceptable inflation rates and also a list of other secondary policy objectives. Athey et al. (2005) construct a model where the monetary authority has private information about the economy and show that optimal policy does allow for limited discretion within a specific range of inflation rates. Athey et al.'s analysis does provide a theoretical rationale for the inflation targeting bands seen in practice.

In the case of New Zealand, the first country to adopt inflation targeting, the policy objectives are explicitly set out in the Policy Target Agreement (PTA) between the Bank and the Minister of Finance with an inflation band currently between 1-3%.

> *"In pursuing its price stability objective, the Bank shall implement monetary policy in a sustainable, consistent, and transparent manner and shall seek to avoid unnecessary instability in output, interest rates and the exchange rate."*[4]

[3]Although the U.K. is the sixth largest economy in terms of total GDP, it is considered to be a small open economy here because economic developments in the U.K. have negligible impacts on the world economy.

[4]Extract from Section 4(b) of the PTA aggrement, 2008, available on the RBNZ website: `http://www.rbnz.govt.nz/monpol/pta/`.

In the U.K., the price stability objective is also made explicit in the monetary policy framework.

> *"The first objective of the central bank is to safeguard the value of the currency in terms of what it will purchase at home and in terms of other currencies. In May 1997 the Government gave the Bank operational independence to set monetary policy by deciding the short-term level of interest rates to meet the Government's stated inflation target - currently 2%."*[5]

As part of the inflation target, the government also set a range for acceptable fluctuations in inflation. If inflation moves outside its target range, the Governor is required to write an open letter to report on the causes for this deviation, the corrective policy action the Bank plans to take, and the time period within which inflation is expected to return to its target range.

In Canada, the main goal is also to keep inflation within a certain target range. Interestingly, the Bank of Canada also express explicit preference for a symmetric target.

> *"The cornerstone of the Bank's monetary policy framework is its inflation-control system, the goal of which is to keep inflation near 2 per cent – the mid-point of a 1 to 3 per cent target range. The Bank is equally concerned with significant movements in the inflation rate, both above the 2 per cent mid-point and below it."*[6]

Similar target band is set in Australia while allowing for natural short-run variation in inflation over the business cycle.

> *"In pursuing the goal of medium-term price stability, both the Reserve Bank and the Government agree on the objective of keeping consumer price inflation between 2 and 3 per cent, on average, over the cycle. This formulation allows for the natural short-run variation in inflation over the cycle while preserving a clearly identifiable performance benchmark over time."*[7]

As argued by Svensson (1999), inflation targeting in practice is never "strict" inflation targeting but always "flexible" inflation targeting. That is, central banks do not only aim to stabilize inflation around the target, but also put some weight on stabilizing other macroeconomic variables such as real output and full employment. The price stability objective is

[5] Bank of England website:
`http://www.bankofengland.co.uk/about/corepurposes/monetary_stability.htm.`

[6] Bank of Canada website:
`http://www.bank-banque-canada.ca/en/monetary/monetary.html.`

[7] Reserve Bank of Australia website:
`http://www.rba.gov.au/monetary-policy/framework/stmt-conduct-mp-4-06122007.html.`

usually explicitly specified and revealed publicly, however, other macroeconomic stabilization objectives and their relative importance are never elucidated. Chapter (4) identifies the macroeconomic objectives, and their relative tradeoffs, for three of the earliest explicit SOE inflation targeters: Australia, Canada and New Zealand. The results show all three central banks share a concern for minimizing the volatility in the change in the nominal interest rate. It also shows that the resulting optimal policy rule responds to exchange rate movements, even in the case where the central banks do not explicitly care about exchange rate stabilization.

2.2.2 Optimal monetary policy

The study of discretion versus commitment in monetary policy has helped promote the use of policy rules to minimize the time inconsistency problem. Henderson and McKibbin (1993), and Taylor (1993) proposed a simple monetary reaction function that responds to changes in the price level, output and/or income.[8] These simple reaction functions had been documented to provide an excellent fit to actual policy behavior, see Clarida et al. (1998, 2000), and Taylor (1999) for the case of the U.S., Plantier and Scrimgeour (2002) for the case of New Zealand, de Brouwer and Gilbert (2005) for Australia, and Ramayandi (2007) for five ASEAN countries. Using a medium scale estimated DSGE model, Adolfson et al. (2008) concludes past policy of the Riksbank tend to be better explained by simple rules rather than optimal policy under commitment.

More recently, the literature has devoted more attention to the study of optimal policy rules rather than simple policy reaction functions. A number of important implications emerge from the work of Clarida et al. (1999) for a closed economy. First, optimal policy embeds inflation targeting in a sense that calls for gradual adjustment to the optimal inflation rate. Second, the nominal interest rate should adjust more than one-for-one with expected inflation. Third, monetary policy can completely offset demand shocks but supply side shocks create a short-run tradeoff between inflation and output variability. Finally, the optimal policy depends critically on the degree of persistence in both inflation and output.

Clarida et al. (2001) extends the discussion to a SOE framework. Interestingly, the SOE model (under certain assumptions) can be reduced down to a two-equation representation (New Keynesian Phillips Curve and IS-type demand equation) similar to the closed economy setup. In such a case, the policy problem for the SOE is isomorphic to the policy problem

[8]These simple reaction functions are often referred to in the literature as Taylor-type reaction functions.

for the closed economy in Clarida et al.'s model. Hence, all the qualitative results from the closed economy carries over to the SOE's case. However, the degree of openness does affect the parameters of the model suggesting a quantitative difference.

In the open economy, a rise in domestic real interest rate induces an appreciation of the terms of trade that lowers domestic demand via the expenditure switching effect. Chapter (6) investigates this transmission channel for the U.K and found significant changes to the international transmission of foreign monetary policy shocks. A higher degree of openness helps strengthen the effect of interest rate changes on domestic output. Under certain parameter restrictions, Gali and Monacelli (2005) show that domestic inflation targeting is superior to both CPI targeting and an exchange rate peg. The intuition is that the excess smoothness in the nominal exchange rate implied by both CPI targeting and the exchange rate peg, combined with the assumed inertia in nominal prices, prevents relative prices from adjusting sufficiently quickly in response to changes in relative productivity. This causes a significant deviation from the first best allocation.

Moving away from Clarida et al., and Gali and Monacelli's restrictive setup, Monacelli (2005) introduced deviations from the law of one price for import prices, by allowing for incomplete exchange rate pass-through. This bears important implications for the design of the optimal monetary policy. First, incomplete pass-through alters the canonical form of the two-equation NK model, and the isomorphic feature between the closed and open economy model is lost. Second, the analysis of monetary policy for an open economy is fundamentally different from that of a closed economy. Allowing for deviations from the law of one price generates an additional endogenous short-run tradeoff between stabilizing inflation and the output gap. Third, optimal commitment policy entails a smoother law of one price gap, hence less volatile exchange rate fluctuations relative to the discretionary outcome. However, the simple Gali and Monacelli and Monacelli (2005) framework does not allow for imported intermediate goods as in McCallum and Nelson (1999) which might be important for SOEs. Chapter (3) provides further discussions on the effects of incomplete pass-through and its implications for the size of the stabilization bias.

2.2.3 Business cycle fluctuations

Stabilization policies are often aimed at mitigating short-run cyclical (or business cycle) fluctuations from some long-run trend. However, determining which part of output variations can be attributed to the cycle and which part to the trend, is not an easy task. Canova (1998) provides an excellent review of the various detrending/filtering methods along with discussions on their advantages and disadvantages. The problem comes down to trying to identify two separate components simultaneously, the trend and the cycle, from a single observed time-series. The alternative detrending methods differ with respect to their identifying assumptions. One common feature, at least with statistical filters, is that the filters remove certain frequencies of the underlying data while amplifying the power of others. The result is smoother cyclical fluctuations that look more like "business cycles". However, high frequency fluctuations induced by frequent economic shocks may also be of economic interest from a stabilization policy point of view.

Economists have developed a number of procedures to overcome the weakness of statistical filters. This often involves applying detrending techniques based on some economic model. First is the common component approach. King et al. (1991) propose a model where the long-run properties of the endogenous variables, such as consumption, real output and investment etc, are driven by a common trend, i.e.: a non-stationary technology shock. More recently, Lubik and Schorfheide (2005) propose a two-country model where output in both countries are driven by a common non-stationary technology shock.

The easiest way to calculate such a decomposition is to estimate a vector error correction model (VECM) and use the cointegrating vector's residuals as the cyclical component. The Beveridge Nelson decomposition essentially does the same thing by assuming a non-stationary shock that drives the trend of output. Another approach is to calculate the cyclical component using the Kalman Filter by assuming some simple structure of the underlying economy. For example, consider that output y_t is made up of a trend, $\tau_t = \gamma + \tau_{t-1} + \eta_t$, and a cyclical component, c_t. Assuming the underlying economy is described by a simple purely backward looking Phillips Curve such that inflation is $\pi_t = \alpha\pi_{t-1} + \beta c_t + \epsilon_t$, where η_t and ϵ_t are i.i.d noise terms and $cov(\eta_t, \epsilon_t) = 0$. One can estimate the parameters α, β, σ_η and σ_ϵ given observations for y_t and π_t, and use the Kalman filter to back out c_t as the cyclical component. The resultant cyclical component will be consistent with some notion of "non-inflationary output gap" measure. The main drawback of using these methods is that the estimates of the trend and cycle differ under different economic specifications.

Figure (2.2) plots the cyclical component of GDP data for Australia, Canada, New Zealand and the U.K. using four different statistical filers: the HP filter with $\lambda = 1600$, the fourth order difference (annual percentage change), a linear filter and a quadratic trend.

As emphasized earlier, depending on the filtering method, the resultant cyclical behavior can be quite different. Furthermore, the second moment of the cycles varies greatly across these detrending methods.

This thesis acknowledges the difficulties and the non-uniqueness problem with extracting the "trend" and "cycle" from a single time-series. Alternative detrending methods can potentially provide a different window through which economists examine the data. It is an ongoing debate as to which one of these windows is the correct one, or more interesting one to look through. Throughout this thesis, where appropriate, the discussion of the results will include some sensitivity analysis with respect to the different detrending methods.

2.3 New open economy macroeconomics

Many inflation targeting economies are small open economies with almost free capital mobility, where shocks originating from the rest of the world are important, and the exchange rate plays a prominent role for macroeconomic stabilization policy aimed at mitigating business cycle fluctuations. The literature on new open economy macroeconomics (NOEM) represent attempts to formalize the analysis of exchange rate determination and international interdependence in the context of Dynamic Stochastic General Equilibrium (DSGE) models.

In contrast to the Mundell-Fleming-Dornbusch type models, NOEM offers a more rigorous treatment of the underlying microfoundations for welfare analysis and policy discussion. Obstfeld and Rogoff (1995), to be discussed later in more detail, is commonly recognized as the contribution that launched this new wave of research. However, several previous studies in this area are also worth mentioning. Svensson and van Wijnbergen (1989) present a stochastic, two country, sticky price model with microfoundations embedded in an intertemporal optimizing setting. McKibbin and Sachs (1989) develop a similar multi-country model that incorporates richer dynamics to address several important policy questions such as the effects of alternative exchange rate arrangements, different monetary policy rules, and international transmission of shocks focusing on inter-country dependence.[9] Models with rigorous microfoundations can also be found in previous studies, notably Stockman (1980), Lucas (1982), Backus et al. (1992, 1994), among others. Lane (2001) and Sarno (2001) provide a more in depth discussion of this literature.

[9] A summary of the results and policy discussions are collected in McKibbin and Sachs (1991).

2.3.1 The Redux model

The baseline Redux model proposed by Obstfeld and Rogoff (1995) is a two country, Dynamic General Equilibrium (DGE) model that allows for nominal price rigidities, imperfect competition, and a representative agent that produces and consumes. Each agent produces a single differentiated good. All agents have identical preferences, characterized by an intertemporal utility function that depends positively on consumption and real money balances but negatively on work effort; effort is positively related to output. There are two impediments to international trade: the law of one price (LOP) holds across individual goods and purchasing power parity (PPP) holds for a basket of goods across the two countries. As a result, LOP and PPP imply a constant real exchange rate (RER) and any temporary variations in the RER are expected to revert back to its long-run level.

Assuming perfect capital markets and only one internationally traded risk-less asset, agents maximize lifetime utility subject to their budget constraints (identical for domestic and foreign agents). Utility maximization gives three fundamental first order conditions (FOCs). The first is the standard intertemporal Euler equation, which relates the marginal utility of consumption to the real interest rate. The second condition is the money market equilibrium condition that equates the marginal rate of substitution between consumption and real money balances, to the opportunity cost of holding money (the nominal interest rate).[10] The third condition requires that the marginal utility from producing an extra unit of output (the real wage) is equal to the marginal disutility of effort, the classic labor-leisure tradeoff equation.

The structure of the price setting mechanism is relatively simple in the baseline Redux model. Firms simultaneously set prices one period in advance. As a result of this fairly arbitrary assumption, all adjustments are completed after one period. With sticky prices, monetary policy can have real effects in the short-run. A domestic monetary expansion will lower the nominal interest rate and the exchange rate depreciates via the uncovered interest parity (UIP) condition. Domestic goods become relatively cheaper compared with foreign goods, generating a temporary increase in demand for domestically produced goods and hence higher output - this is the expenditure switching effect. On the production side, monopolistic producers will set prices above the marginal cost and it is profitable to meet the unexpected demand at the prevailing price level given the fixed wage cost.

[10]The representative agent directly benefits from holding money in the utility function but loses the interest rate on the riskless bond as well as the opportunity to eliminate the cost of inflation.

The literature has largely focused on the two country version of the model, which allows for explicit analysis of international interdependence and endogenous determination of interest rates and asset prices. However, this comes at a considerable cost in terms of model complexity that may not be of great importance in analyzing SOEs. Obstfeld and Rogoff (1995) also presented a simple example of a SOE model where output is separated into tradable and nontradable goods. Both of these enter into the consumer's sub-utility function via log separable preferences. In this simple model, monopolistic competition only exists in the nontradable goods sector, whereas the tradable goods sector is characterized by a single homogenous product that sells for the same price in the perfectly competitive world market.[11] Unlike the two country Redux model, the discount rate is tied down by the level of world interest rate (exogenous to the SOE) implying a flat optimal consumption path for tradable goods. In this case, exchange rate overshooting may occur. Since monetary shocks do not produce a current account imbalance, money is neutral in the long run and the nominal exchange rate changes are proportionate to the change in the money stock. If the elasticity of money demand is less than 1, the nominal exchange rate overshoots its long-run level following relative money supply shocks.

Lane (1997) applies this SOE model to examine discretionary monetary policy and the impact of openness (proxied by the relative size of the tradable sector) on the equilibrium inflation rate. A more open economy with a larger tradable sector gains less from "surprise inflation" because the output gain from the monetary expansion is only limited to the nontrabable sector where nominal rigidities exist. However, the SOE-Redux model used in Lane's (1997) analysis does not account for imperfect exchange rate pass-through from nominal rigidities. Chapter (3) extends Lane's analysis to an empirical DSGE model with nominal rigidities in both domestically produced and imported goods. The case study tries to further understand the nature of the policy tradeoffs, and the size of the stabilization bias for a SOE relative to its closed economy counterpart.

2.3.2 Workhorse New Keynesian open economy model

Subsequent work on NOEM has modified or extended many of the assumptions and features of the baseline Redux model largely motivated by the need to match the historical data. This subsection reviews some of the key contributions of this growing literature.

[11]The domestic price of tradable goods is equal to the exogenous world price multiplied by the nominal exchange rate.

2.3.2.1 Nominal rigidities

The baseline Redux model assumes prices are sticky for only one period. There has been a growing emphasis on both nominal price and wage rigidities. Hau (2000) considers the case where prices are flexible but nominal wages are predetermined. Each household supplies a differentiated labor input and monopolistic firms set prices as a constant markup over the wage. As a result, optimal prices will inherit the stickiness from predetermined wages and remain fixed in the short-run. Labour market rigidities produce the same international transmission effects as price rigidity in the baseline Redux model.

Many NOEM models have introduced the staggered price assumption first suggested by Calvo (1983) to capture the smooth, rather than discrete, aggregate price level adjustments. Calvo price setting assumes in any period t, only a fraction of the firms are able to reset their prices optimally, while others keep their prices fixed. The opportunity to adjust prices arrives stochastically for each firm is independently across the firms and time. As a result, the aggregate price level is a smooth variable and changes only gradually over time. Kollman (1997) uses a model with sticky prices and wages to explore the behavior of the exchange rates and prices in response to monetary policy shocks. The results suggest that Calvo-type nominal rigidities are better in matching the high serial correlation of nominal and real exchange rates, and the gradual adjustment of the price level. However, it does less well in matching the cross correlations of output with other macroeconomic variables. Andersen (1998) points out that staggered wages can generate more persistence than staggered prices.

While staggered prices and wages can generate smooth and gradual adjustments of the price level, they fail to account for the smooth and persistent behavior of inflation. To capture this, the standard Calvo mechanism is modified to allow for non-optimizing firms to index their prices with some reference to past inflation rates, see Woodford (2003), Smets and Wouters (2003), and Christiano et al. (2005). In addition to the popular Calvo-type staggered prices, Mankiw and Reis (2002, 2007), Ball et al. (2005) and Arslan (2008) hypothesize that the observed inflation inertia comes from sticky information rather than sticky prices. Nevertheless, both sticky prices and sticky information generate similar functional form for the inflation process. This is often referred to as the New Keynesian Phillips Curve (NKPC), which represents a crucial building block in modern macroeconomic models.

2.3.2.2 Imperfect exchange rate pass-through

The discussion in the previous subsection largely focused on the role of nominal rigidities in domestic product and factor markets. The overall price level in an open economy also includes imported goods. In most industrialized countries, imported goods make up a significant proportion of the consumer's consumption basket, see the import-to-GDP ratio for selected countries in Table (2.1). Japan has the smallest import-to-GDP ratio of 11% followed by the US with 17%, while Luxembourg's ratio is over 150%. Most of the inflation targeting countries have an import-to-GDP ratio between 30-50%.

For an open economy, it is useful to distinguish the difference in the source of nominal rigidities between domestically produced and imported goods. For example, Monacelli (2005) allows for monopolistic competition in the importing sector. While competition in the world market may bring import prices close to the marginal cost at the "dock", but monopolistic importers can set final prices away from the world price to generate a wedge across countries. Rigidities in the importing sector gives rise to incomplete exchange rate pass-through which has important implications for the central bank's stabilization problem.

2.4 Towards new open economy macroeconometrics

Empirical studies in the area of open economy analysis have largely focused on trying to distinguish between various competing assumptions, either via calibration or direct econometric investigation (or a combination of the two). More recently, the focus has shifted slightly towards building models with a better empirical fit to complement existing tools for policy evaluation and forecasting analysis. This section provides an overview of this rich literature focusing on the estimation and evaluation of DSGE models.

2.4.1 Parameter calibration and estimation

Earlier open economy analysis follows the RBC literature quite closely in parameterizing the model. This usually involves first specifying a collection of empirical regularities ("stylized facts") that the model is designed to account for. A set of structural parameters is choosen to match a subset of these stylized facts, then conditional on the model's parameterization, verify whether the model can replicate other empirical regularities in the data. One such criterion is to match the unconditional moments generated by the model to the unconditional moments observed in the data as in Chari et al. (2002) for an open economy model.

Although useful in gaining empirical insights, this approach does not provide an overall evaluation of model fit and it is difficult to formally assess its statistical validity. More recently, methods have been developed to confront the model directly with the data. This thesis focuses on two popular estimation procedures: maximum likelihood estimation and Bayesian estimation.

The maximum likelihood estimation (MLE) approach utilizes all the information available from the data and inference on the model's parameters can be directly obtained from the likelihood function. Examples in using MLE for estimating DSGE models include Ireland (1997, 2004), Schorfheide (2000), Fuhrer (2000) and Christiano et al. (2005). Unfortunately, numerical maximization of the likelihood is often very difficult in practice due to the identification problems inherent in DSGE models and nonlinearity in parameters. For example, two structural parameters that enter the model only proportionally will not be recoverable, and the likelihood function will be "flat" in some dimensions of the parameter space. To cope with the problem, researchers often fix a subset of the parameters and try to estimate the rest. Canova and Sala (2006) provide a more detail discussion of the identification issue in DSGE models.

The use of Bayesian methods has become very popular following the work of Smets and Wouters (2003), Rabanal and Rubio-Ramírez (2005), and Lubik and Schorfheide (2005, 2007). A review of the literature can be found in An and Schorfheide (2007). The idea behind Bayesian analysis is to combine the information contained in the data (likelihood function) with prior information (prior distribution) in the estimation of the parameters. Inference is based on the posterior distribution of the model (the likelihood weighted by the prior distribution) and various statistics of interest, such as IRFs, can be simulated from the posterior draws.[12] Another often cited advantage of using Bayesian methods is that the posterior distribution provides a probabilistic representation of the parameter and model space. On the practical front, adding priors introduce "curvature" into the objective function making maximization of the posterior much easier than the likelihood function alone. Case studies presented in Chapters (3) and (4) make extensive use of this estimation method.

However, Bayesian methods also suffer from several drawbacks. First, a tightly specified

[12]Usually no closed form is available for calculating the posterior distribution, instead, it is simulated using the Metropolis-Hastings algorithm.

prior can in fact produce a well behaved posterior distribution, even if the likelihood function has little information, giving the econometrician the illusion that he/she have collected useful evidence, i.e. a very small standard error for the estimated coefficient. Second, employing prior distributions that do not truly reflect the existing location uncertainty, may hide identification problems. Third, it is often difficult to obtain good information to build the priors on, choosing them arbitrarily defeats the purpose of using any prior at all.

2.4.2 Model comparison and evaluation

The ultimate goal of working with DSGE models is to provide reliable quantitative answers to substantive economic policy questions. In addition to the ability to correctly estimate the underlying structural parameters (model estimation), another challenging task is the ability to distinguish competing theories and model assumptions to assess the fit of the underlying model (model evaluation).

The first approach is to assess the absolute model fit based on the predictive density of the model - the classical approach. If the data lies in the tails of the model's predictive distribution, this serves as evidence against the current model relative to other alternatives. Other diagnostic statistics such as the model's unconditional moments, auto and cross correlations are also useful. Lees et al. (2007) use this strategy to assess the empirical fit of an estimated DSGE-VAR model.

The second approach is based on the posterior odds (the ratio of the marginal data densities multiplied by the prior odds) of various competing models. Researchers can place prior probabilities on competing models, and assess alternative specifications using the posterior odds. The marginal data density can be approximated using Geweke's (1999) modified harmonic mean estimator. Chapter (4) makes use of this approach to assess whether exchange rate movement enters the central bank's objective function.

2.5 Statistical VAR models

Two distinct approaches to macroeconomic analysis emerged during the early 1980s and continues to drive the literature today. One approach follows the work of Kydland and Prescott (1982) in using DSGE models which were discussed in section (2.4) . The alternative follows the work of Sims (1980) in characterizing the co-movements in key aggregate variables using VAR models. Both of these approaches have their distinct strengths and weaknesses. DSGE models for instance, are constructed based on firmly grounded micro-founded economic theory. These models generally draw a tight link between the structural parameters and the time-series behavior of aggregate macroeconomic variables. However, DSGE models are often described as too "rigid" when taken to the data. VAR models, on the other hand, tend to be more flexible and can be easily estimated to help address a wide range of policy questions. Examples of VAR studies include Cushman and Zha (1997), Monticelli and Tristani (1999), Dungey and Pagan (2000), Buckle et al. (2002), Faust and Rogers (2003), and Farrant and Peersman (2006).

2.5.1 Identification problems

The flexibility of VAR models also poses important drawbacks. VAR specifications often require little, if any, reference to detailed economic theory. As a consequence, results are often hard to interpret and difficult to relate back to the underlying economic question. Many studies have tried drawing closer links with economic theory to identify the shocks of economic interest. However, this remains a controversial topic, where different identifying assumptions can lead to quite different conclusions. Several recent papers in the international transmission literature have proposed alternative identification structures including, amongst others, the recursive schemes in Grilli and Roubini (1995), Eichenbaum and Evans (1995), and Faust and Rogers (2003), the non-recursive schemes in Cushman and Zha (1997), Dungey and Pagan (2000), Kim and Roubini (2000), and Kim (2001).

To see where the problem lies, consider the following general VAR(p) model with n variables Y_t:

$$BY_t = A(L)Y_{t-1} + \epsilon_t \tag{2.5}$$

where: $A(L) = A_1L + \cdots + A_pL^p$ is an p^{th} order matrix polynomial; B is an $(n \times n)$ matrix of coefficients that reflect the contemporaneous relationships among Y_t; and ϵ_t is a set of $(n\times 1)$ normally distributed structural disturbances with mean zero; and variance covariance matrix Σ, $\Sigma_{i,j} = 0 \; \forall i \neq j$. The structural representation in Equation (2.5) has the following reduced form:

$$Y_t = \Pi(L)Y_{t-1} + e_t \tag{2.6}$$

where $\Pi(L) = B^{-1}A(L)$ and e_t is a set of $(n \times 1)$ normally distributed reduced-form errors with mean zero and variance covariance matrix V, $V_{i,j} \neq 0 \; \forall i, j$. The identification procedure involves mapping the statistical relationships summarised by the reduced form errors e_t back into economic relationships described by ϵ_t. Let $P = B^{-1}$. The reduced form errors are related to the structural disturbances in the following manner:

$$e_t = P\epsilon_t \quad \text{and} \quad V = E(e_t e_t') = HH' \tag{2.7}$$

for some matrix H such that $HH' = P\Sigma P'$. An identification problem arises if there are not enough restrictions to uniquely pin down H from the matrix V.[13] However, there are an infinite number of ways in which this orthogonality condition can be achieved. Let H be an orthogonal decomposition of $V = HH'$. The multiplicity arises from the fact that for any orthonormal matrix Q (where $QQ' = I$), such that $V = HQQ'H' = \tilde{H}\tilde{H}'$ is also an admissible decomposition of V.

One example is the Choleski factor of V, where $H = chol(V)$ and the set of economic disturbances is $e_t = H\epsilon_t$. Another example of such orthogonal representation is the eigenvalue-eigenvector decomposition of $V = \Gamma\Lambda\Gamma' = \tilde{H}\tilde{H}'$, where Γ is a matrix of eigenvectors and Λ is a diagonal matrix of eigenvalues. In which case, $\tilde{H} = \Gamma\Lambda^{1/2}$, need not be a lower triangular matrix. This decomposition does not have any economic content, but nevertheless, produces a set of uncorrelated shocks $e_t = \tilde{H}\epsilon_t$, without imposing zero-type restrictions. It is obvious that different decompositions will produce a different set of structural disturbances, and hence a different vector moving average (VMA) representation.[14]

Another approach is to impose the DSGE restrictions directly on the VAR's IRFs, Chapter (5) investigates the validity of this proposal using the sign restriction method. Some earlier studies have attempted this, though using a slightly different approach. McKibbin et al. (1998) use the McKibbin-Sachs Global (MSG2) model to restrict the long run behavior of a VAR while the short run features are left unconstrained. Peersman and Straub (2004) use a calibrated RBC model to derive sign restrictions to help identify technology shocks. Dungey and Fry (2009) uses similar methodology to identify both monetary and fiscal policy shocks. In terms of methodological contribution, Chapter (5) tries to identify a full set of domestic and international shocks, and demonstrates how to impose the SOE assumption using the sign restriction identification scheme. The results show that international factors contribute over half of the output forecast errors whereas demand shocks have relatively modest effects.

[13] There are n^2 unknowns elements in H with only $n(n+1)/2$ unique elements in V.

[14] Typical summary statistics from VAR studies are usually functions of the underlying VMA representation.

2.5.2 Large information set

Most of the contributions discussed above were based on VAR models with only a few selected variables. Arguably, central banks across the world monitor (and possibly respond to) a far wider information set than typically assumed in these small-scale VARs. To overcome this, Boivin and Giannoni (2008), and Mumtaz and Surico (2009) extend the Factor-Augmented VAR (FAVAR) model proposed by Bernanke et al. (2005) to the open economy setting. The FAVAR model helps address the limited information problem, in particular, Mumtaz and Surico (2009) found many of the open economy anomalies disappear when a large panel of data is used. However, a common assumption is that both the stochastic driving process's volatility and the nature of co-movement among the variables does not change over time.[15]

Many studies have documented significant declines in the output and inflation volatility since the mid-1980's, a phenomenon known as the "great moderation". In addition, the level and persistence of inflation has stayed around historical lows. Therefore, it is unsatisfactory to simply assume the size and the transmission mechanism of international shocks has not changed over this period. Chapter (6) extends the open economy FAVAR models with time-varying coefficients and stochastic volatility to examine possible changes to the international transmission mechanism.

2.6 Conclusion

This Chapter provides an overview of the motivations and objectives behind macroeconomic stabilization policies, focusing on the role of monetary policy. The theoretical literature has advanced quickly in the last 10 years to provide a class of open economy models. At the same time, the empirical literature has also kept pace with the theoretical developments to provide a set of tools for estimating and comparing various quantitative models. Although challenges remain, these developments have provided researchers and policymakers with an useful set of tools to tackle important policy questions. This thesis utilizes these tools to address the stabilization problem related to small open economies.

[15]Boivin and Giannoni (2008) estimates the model over two sub-periods by introducing a dummy variable.

Table 2.1: Export and import ratio for OECD countries in 2005

COUNTRY	Imports to GDP ratio	COUNTRY	Imports to GDP ratio
Australia	0.30	Korea	0.45
Austria	0.52	Luxembourg	1.51
Belgium	0.86	Mexico	0.37
Canada	0.41	Netherlands	0.71
Czech Republic	0.88	New Zealand	0.43
Denmark	0.48	Norway	0.32
Finland	0.38	Poland	0.37
France	0.30	Portugal	0.42
Germany	0.38	Slovak Republic	0.94
Greece	0.27	Spain	0.37
Hungary	0.92	Sweden	0.41
Iceland	0.48	Switzerland	0.43
Ireland	0.82	Turkey	0.39
Italy	0.26	United Kingdom	0.34
Japan	0.11	United States	0.17

Figure 2.1: Annual change in inflation for inflation targeting (IT) countries

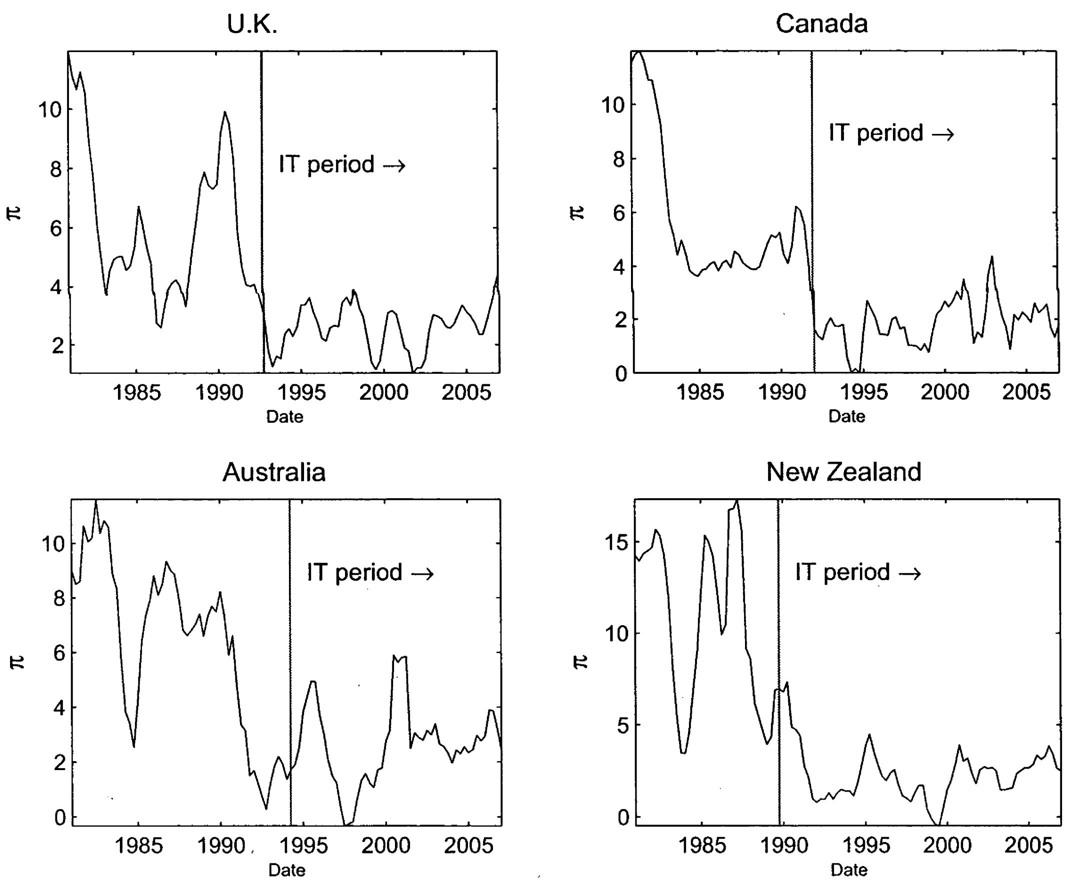
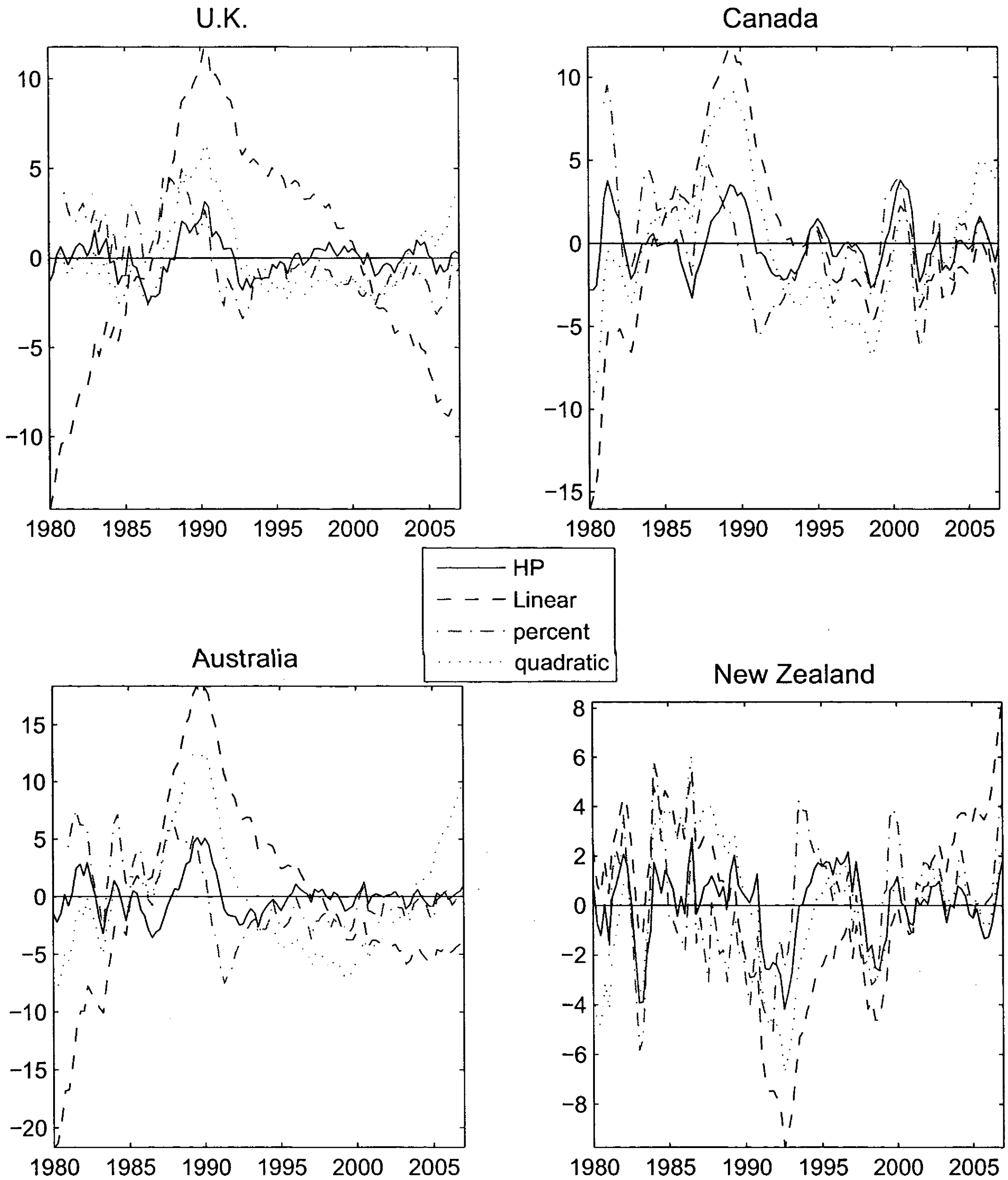


Figure 2.2: Business cycle using various filtering methods



CHAPTER 3

STABILIZATION BIAS FOR A SMALL OPEN ECONOMY: THE CASE OF NEW ZEALAND

Abstract*

Using a a fully specified DSGE model, this paper explores the relationship between a central bank's policy objectives and the stabilization bias. The model is estimated using data from New Zealand. Results indicate that the size of the stabilization bias is nearly twice as large for a small open economy (SOE) relative to that usually found for closed economies. The results also indicate that the size of the stabilization bias is increasing with the policymaker's preference for stabilizing exchange rate fluctuations.

3.1 Introduction

ROMER 1993 highlighted an important empirical regularity that the average rate of inflation is a decreasing function of trade openness. Romer attributes this to the higher cost of discretionary monetary policy in a more open economy. Since then, the study of commitment and discretionary monetary policy has moved beyond the static framework to incorporate realistic persistence in output, inflation and other nominal rigidities. This paper investigates the possible links between policy objectives and the size of the stabilization bias for a small open economy (SOE).

This is potentially interesting for several reasons. The analysis uses an estimated dynamic stochastic general equilibrium (DSGE) model to provide a realistic estimate of the

*An earlier version of Chapter (3) was previously published as "Gains From Commitment Policy For A Small Open Economy: The Case Of New Zealand", CAMA Working Paper 2006-25.

size of the stabilization bias for an actual economy. The evidence can be used as a possible explanation for the motivation behind why many SOEs have chosen to adopt inflation targeting.[1] Insights from the analysis are also linked to the influential work by Romer (1993) and it extends the discussion to a fully dynamic optimizing framework.

While the literature has largely focused on the case of a closed economy, the stabilization problem faced by a SOE central bank differs in two important dimensions. First, in addition to domestic supply and demand shocks, the SOE is also subject to various foreign disturbances. Second, the exchange rate implies an additional transmission channel for monetary policy as well as an indirect channel for the transmission of foreign shocks to the domestic economy.

Clarida et al. (2001) use a simple canonical New Keynesian model to show that the SOE's optimal monetary policy design problem is isomorphic to that of a closed economy. That is, the nature of the underlying output and inflation tradeoff remains the same. More recently, Monacelli (2005) points out that this is no longer true once incomplete pass-through in import prices is incorporated into the model. Allowing for incomplete pass-through bears important implications for the design of the optimal monetary policy. Deviations from the law of one price (or purchasing power parity) generates an additional endogenous short-run tradeoff between stabilizing inflation and the output gap. In an attempt to further understand the nature of this policy tradeoff, two key questions are studied in this paper: the empirical importance of the size of the stabilization bias for a SOE; and the relationship between the stabilization bias and policy objectives of the central bank.

A number of empirical studies have examined the size of the stabilization bias as a proxy for the costs of discretionary policy relative to the commitment case (pre-commitment).[2] Dennis (2004b) measures the improvement from pre-commitment using Clarida et al.'s (1999) closed economy model to be between 0% to 11%; Ehrmann and Smets (2003) use a New Keynesian model calibrated to the Euro area and measure the gains from commitment to be between 17% and 31%. Using the *inflation equivalent* measure, Dennis and Soderstrom (2006) consider four models estimated using US data and find the size of the bias ranges from 0.05 to 3.6 percentage point of inflation. Dennis and Soderstrom also stress the size of the stabilization bias depends critically on the model as well as the underlying

[1] Since the 1990's many SOEs have adopted an institutional framework that emphasizes inflation targeting. No country that has adopted it has abandoned it (Truman, 2003), and the numbers are expected to grow.

[2] The terms "stabilization bias" and "gains from pre-commitment", measured as the difference in the loss function between commitment and discretion equilibrium, are used inter-changeably.

parameters describing the economy. Lees (2007) estimates the size of the stabilization bias for New Zealand to be around 1 percentage point.

Open economy empirical findings so far, such as Lees (2007), are based on models that lack rich microfoundations. These features are now crucial building blocks in modern workhorse macroeconomic models for policy analysis. This paper presents a fully specified DSGE model estimated using New Zealand data as the vehicle for discussion. As a point of departure, the paper also provides an empirical distribution for the size of the stabilization bias as opposed to just a point estimate.

New Zealand was the first country to explicitly adopt an inflation targeting framework under the Reserve Bank of New Zealand (RBNZ) Act in 1989 with the aim of bringing inflation down to a specific target range. The establishment of the Act generated a great deal of interest among both policy makers and researchers in the early 1990s. In addition to the inflation target, the Policy Target Agreement (PTA) was updated in 1999 to reflect the desire to minimize unnecessary variations in the exchange rate as well as variations in output and interest rates.[3] This legislative framework closely resembles the literature on modeling the behavior of a central bank using a loss function. While the quantitative results drawn here are specific to the case of New Zealand, insights and the policy discussions are also applicable to other SOEs.

Two interesting results emerge from the analysis. First, the estimated size of the stabilization bias for a SOE is found to be nearly twice as large relative to that usually found in the closed economy counterpart. As the economy becomes more open, the cost of discretionary policy relative to commitment equilibrium is higher. Second, the size of the stabilization bias increases with the policymaker's preference for stabilizing exchange rate fluctuations.

The paper is organized as follows. Section (3.2) outlines the small open economy model. Section (3.3) discusses the estimation methodology and describes the data. Section (3.4) presents the parameter estimation results. Section (3.5) estimates the size of the stabilization bias together with some policy discussions. Finally, Section (3.6) contains concluding remarks.

[3] See section 4(c) of the Reserve Bank of New Zealand PTA, 1999.

3.2 A small open economy model

This section describes the key structural equations implied by the model proposed by Gali and Monacelli (2005) and Monacelli (2005). The model's dynamics are enriched by allowing for external habit formation and indexation of prices, as in Smets and Wouters (2003), and Christiano et al. (2005).

3.2.1 Households

The economy is inhabited by a representative household who seeks to maximize:

$$E_0 \sum_{t=0}^{\infty} \beta^t \{U(C_t) - V(N_t)\} \tag{3.1}$$

$$U(C_t) = \frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} \quad \text{and} \quad V(N_t) = \frac{N_t^{1+\varphi}}{1+\varphi}$$

where β is the rate of time preference, σ is the inverse elasticity of intertemporal substitution, and φ is the inverse elasticity of labour supply. N_t denotes hours of labour, and hC_{t-1} represents habit formation for the optimizing household, for $h \in [0,\ 1]$. C_t is a composite consumption index of foreign ($C_{F,t}$) and domestically ($C_{H,t}$) produced goods defined as:

$$C_t \equiv \left((1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{3.2}$$

where $\alpha \in [0,\ 1]$ is the import ratio measuring the degree of openness, and $\eta > 0$ is the elasticity of substitution between home and foreign goods. The household's maximization problem is completed given the following budget constraint at time t:

$$\int_0^1 \{P_{H,t}(i)C_{H,t}(i) + P_{F,t}(i)C_{F,t}(i)\}di + E_t\{Q_{t,t+1}D_{t+1}\} \leq D_t + W_t N_t \tag{3.3}$$

for $t = 1, 2, \ldots, \infty$, where $P_{H,t}(i)$ and $P_{F,t}(i)$ denote the prices of domestic and foreign good $i \in [0,\ 1]$ respectively, $Q_{t,t+1}$ is the stochastic discount rate on nominal payoffs, D_t is the nominal payoff on a portfolio held at $t-1$ and W_t is the nominal wage.[4]

Solving the household's optimization problem yields the following set of first order conditions (FOCs):

$$(C_t - hC_{t-1})^{-\sigma} \frac{W_t}{P_t} = N_t^{\varphi} \tag{3.4}$$

[4]The consumption basket is aggregated over all i goods, $i \in [0,\ 1]$.

$$\beta R_t E_t \left\{ \frac{P_t}{P_{t+1}} \left(\frac{C_{t+1} - hC_t}{C_t - hC_{t-1}} \right)^{-\sigma} \right\} = 1 \tag{3.5}$$

where $R_t = 1/E_t Q_{t,t+1}$ is the gross nominal return on a riskless one-period bond maturing in $t + 1$ and $P_t = \left[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$ is the Consumer Price Index (CPI). The intra-temporal optimality condition (3.4) states that the marginal utility of consumption is equal to the marginal value of labour at any one point of time; (3.5) gives the Euler equation for inter-temporal consumption.

Households in the foreign economy are assumed to face exactly the same optimization problem with identical preferences. The only difference being that the influence from the other economy is negligible.One can arrive at a similar set of optimality conditions describing the dynamic behaviour of key variables in the foreign economy. Foreign sector variables are denoted by $*$.

3.2.2 Inflation, the real exchange rate and terms of trade

Throughout this paper, the assumption of the *law of one price* (LOP) holds for the export sector, but incomplete pass-through for import prices is allowed. The motivation behind this assumption is that the small open economy is a price taker with little bargaining power in the international markets. For its export bundle, prices are determined exogenously in the rest of the world. On the import side, competition in the world market brings import prices close to the marginal cost at the wholesale level, but rigidities arising from inefficient distribution networks and monopolistic retailers allows domestic retail import prices to deviate from the world price. Burstein et al. (2003) provide a similar argument, which is supported using United States (US) data.

The *terms of trade* (TOT) are defined as $S_t = \frac{P_{F,t}}{P_{H,t}}$ (or in logs $s_t = p_{F,t} - p_{H,t}$).[5] Log-linearizing the CPI formula around the steady state and taking the first difference yields the following identity linking CPI-inflation, domestic inflation ($\pi_{H,t}$) and the change in the TOT:

$$\Delta s_t = \pi_{F,t} - \pi_{H,t} \tag{3.6}$$

The change in the TOT is proportional to the difference between import and domestic inflation. In addition, $\mathcal{E}_t$ is the nominal exchange rate (expressed in terms of foreign currency

[5]The terms of trade is thus the price of foreign goods per unit of home good. An increase in s_t is equivalent to an increase in competitiveness for the domestic economy because foreign prices increase and/or home prices fall.

per unit of domestic currency).[6] Similarly, the real exchange rate and the law of one price (LOP) gap are defined as $\zeta_t \equiv \frac{\mathcal{E}_t P_t}{P_t^*}$ and $\Psi_t = \frac{P_t^*}{\mathcal{E}_t P_{F,t}}$ respectively. If the LOP holds, i.e. if $\Psi_t = 1$, then the import price index $P_{F,t}$ is the foreign price index divided by $\mathcal{E}_t$, or $P_{F,t} = \frac{P_t^*}{\mathcal{E}_t}$. The LOP gap is a wedge or inverse mark-up between the *world* price of world goods and the *domestic* price of these imported world goods. Substituting the definition of the CPI, s_t and $\psi_t = \ln(\Psi_t)$ into $q_t = \ln(\zeta_t)$ gives:

$$\begin{aligned} q_t &= e_t + p_t - p_t^* \\ &= -\psi_t - (1-\alpha)s_t \end{aligned} \tag{3.7}$$

$$\Rightarrow \psi_t = -[q_t + (1-\alpha)s_t]$$

Consequently, the LOP gap is inversely proportionate to the real exchange rate and the degree of international competitiveness for the domestic economy.

Under the assumption of complete international financial markets and perfect capital mobility, the expected nominal return from risk-free bonds, in domestic currency terms, must be the same as the expected domestic-currency return from foreign bonds, that is $E_t Q_{t,t+1} = E_t(Q_{t,t+1}^* \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t})$. Using this relationship, the intertemporal optimality conditions can be equated for the domestic and foreign households' optimization problem. Assuming the same habit formation parameter across the two countries gives a similar international risk sharing condition as in Gali and Monacelli (2005) under external habit formation:

$$C_t - hC_{t-1} = \vartheta(C_t^* - hC_{t-1}^*)\zeta_t^{-\frac{1}{\sigma}} \tag{3.8}$$

where ϑ is a constant depending on initial asset positions. Log-linearizing equation (3.8) around the steady state gives:

$$c_t - hc_{t-1} = (y_t^* - hy_{t-1}^*) - \frac{1-h}{\sigma}q_t \tag{3.9}$$

Under the small open economy assumption, trade with the domestic economy is assumed to have a negligible impact on the foreign economy such that $c_t^* = y_t^*$. The assumption of complete international financial markets and perfect capital mobility leads to a simple relationship linking the domestic economy with world output and the real exchange rate. Furthermore, these assumptions help recover another important relationship, the *uncov-*

[6] An increase in $\mathcal{E}_t$ means an appreciation of the domestic currency.

ered interest parity (UIP) condition:

$$E_t\left(Q_{t,t+1}\left\{R_t - R_t^*\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}}\right\}\right) = 0 \tag{3.10}$$

Log linearizing around the perfect foresight steady state yields the familiar UIP condition for the real exchange rate:[7]

$$E_t\Delta q_{t+1} = -\left\{(r_t - E_t\pi_{t+1}) - (r_t^* - E_t\pi_{t+1}^*)\right\} \tag{3.11}$$

that is, the expected change in q_t depends on the current real interest rate differentials.

3.2.3 Firms

3.2.3.1 Production technology

There is a continuum of identical monopolistically-competitive firms; the j^{th} firm produces a differentiated good, Y_j, using a linear production function:

$$Y_t(j) = A_t N_t(j) \tag{3.12}$$

where $a_t \equiv \log A_t$ follows an AR(1) process, $a_t = \rho_a a_{t-1} + \nu_t^a$, describing the firm-specific productivity index. Aggregate output can be written as

$$Y_t = \left[\int_0^1 Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}. \tag{3.13}$$

where $\varepsilon > 1$ is the elasticity of substitution among varieties. Given each firm has the same technology, the real total cost of production is $TC_t(j) = \frac{W_t}{P_{H,t}}\frac{Y_t(j)}{A_t}$. Hence, the real marginal cost, $MC_t(j) = \frac{W_t}{A_t P_{H,t}}$, will be common across all domestic firms. Substituting the intertemporal Euler equation (3.4) and the production function (3.12) into the marginal cost equation, after log-linearizing we obtain:

$$mc_t = \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \varphi y_t + \alpha s_t - (1+\varphi)a_t \tag{3.14}$$

Thus, marginal cost is an increasing function of domestic output and s_t, and is inversely related to the level of labour productivity.

[7]The risk premium is assumed to be constant in the steady state.

3.2.3.2 Price setting behaviour and incomplete pass-through

Domestic firms

In the domestic economy, monopolistic firms are assumed to set prices in a Calvo-staggered fashion. In any period t, only $1 - \theta_H$, where $\theta_H \in [0,1]$, fraction of firms are able to reset their prices optimally, while the other fraction θ_H cannot. Instead, the latter are assumed to adjust their prices, $P_t^I(j)$, by indexing it to last period's inflation as follows:

$$P_{H,t}^I(j) = P_{H,t-1}(j)\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta_H} \tag{3.15}$$

where $\delta_H \in [0,\ 1]$ is the degree of price indexation to the previous period's inflation rate.[8] Consider only the symmetric equilibrium case since all domestic firms face the same pricing problem, that is $P_{H,t}(j) = P_{H,t}(k),\ \forall j,k$. Let $\bar{P}_{H,t}$ denote the price level that an optimizing firm sets each period. The evolution of the aggregate home goods price index is defined as:

$$P_{H,t} = \left\{(1-\theta_H)\left(P_{H,t}\right)^{1-\varepsilon} + \theta_H\left[P_{H,t-1}\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta_H}\right]^{1-\varepsilon}\right\}^{\frac{1}{1-\varepsilon}} \tag{3.16}$$

When setting the new price, in period t, an optimizing firm will seek to maximize the current value of its dividend stream subject to the sequence of demand constraints such that:

$$\max_{P_{H,t}(j)}\sum_{k=0}^{\infty}(\theta_H)^k E_t\left\{Q_{t,t+k}Y_{t+k}(j)\left[P_{H,t}(j)\left(\frac{P_{H,t+k-1}}{P_{H,t-1}}\right)^{\delta_H} - P_{H,t+k}MC_{t+k}\right]\right\} \tag{3.17}$$

$$\text{subject to}\quad Y_{t+k}(j) \leq \left[\frac{P_{H,t}(j)}{P_{H,t+k}}\left(\frac{P_{H,t+k-1}}{P_{H,t-1}}\right)^{\delta_H}\right]^{-\varepsilon}\left(C_{H,t+k} + C_{H,t+k}^*\right)$$

where MC_{t+k} is the real marginal cost faced by each firm and the effective stochastic discount rate is now $\theta_H^k E_t Q_{t,t+k}$ to take into account firms have a θ_H probability of not being able to reset prices each period. The corresponding first order condition can be written as:

$$\sum_{k=0}^{\infty}\theta_H^k E_t\left\{Q_{t,t+k}Y_{t+k}\left[\bar{P}_{H,t}\left(\frac{P_{H,t+k-1}}{P_{H,t-1}}\right)^{\delta_H} - \frac{\varepsilon}{\varepsilon-1}P_{H,t+k}MC_{t+k}\right]\right\} = 0 \tag{3.18}$$

where $\frac{\varepsilon}{\varepsilon-1}$ is the real marginal cost if prices were fully flexible. Log linearizing equation

[8] Christiano et al. (2005) assume $\delta_H = 1$, here it is left unrestricted to determine the degree of backward lookingness in the Phillips Curves.

(3.18) yields the following New Keynesian Phillips Curve (NKPC).[9]

$$\pi_{H,t} = \frac{1}{1+\beta\delta_H}\left(\beta E_t \pi_{H,t+1} + \delta_H \pi_{H,t-1} + \lambda_H mc_t\right) \tag{3.19}$$

where $\lambda_H = \frac{(1-\beta\theta_H)(1-\theta_H)}{\theta_H}$. The Calvo pricing structure yields a familiar NKPC, where domestic inflation has a forward looking and backward-looking component depending on the degree of price indexation. On the other hand, the elasticity of domestic inflation with respect to changes in the marginal cost depends on the frequency of price adjustments, the sticky price parameter θ_H.

Import retail firms

For the import retailing sector, it is assumed the LOP holds at the wholesale level. However, inefficiency in distribution channels together with monopolistic retailers keep domestic import prices over and above the marginal cost (the world price). As a result, the LOP fails to hold at the retail level for domestic consumers. Following a similar Calvo-pricing argument as before, an import retailer will try and maximize the following objective function subject to domestic import demand:

$$\max_{P_{F,t}(j)} \sum_{k=0}^{\infty} (\theta_F)^k E_t \left\{ Q_{t,t+k} C_{F,t+k}(j) \left[P_{F,t}(j) \left(\frac{P_{F,t+k-1}}{P_{F,t-1}} \right)^{\delta_F} - \frac{P^*_{t+k}(j)}{\mathcal{E}_{t,k}} \right] \right\} \tag{3.20}$$

$$\text{subject to} \quad C_{F,t+k}(j) \leq \left[\frac{P_{F,t}(j)}{P_{F,t+k}} \left(\frac{P_{F,t+k-1}}{P_{F,t-1}} \right)^{\delta_H} \right]^{-\varepsilon} C_{F,t+k}$$

where P^*_{t+k} is the world competitive price in foreign currency, $\theta_F \in [0,\ 1]$ is the fraction of importer retailers that cannot re-optimize their prices every period, $\delta_F \in [0,\ 1]$ is the degree of price indexation in the import retailing sector and both θ_H and δ_H are allowed to differ from its domestic counterpart. Recall the LOP $\Psi_t = \frac{P^*_t}{\mathcal{E}_t P_{F,t}}$, the corresponding first order condition can be written as:

$$\sum_{k=0}^{\infty} \theta_F^k E_t \left\{ Q_{t,t+k} C_{F,t+k} \left[\bar{P}_{F,t} \left(\frac{P_{F,t+k-1}}{P_{F,t-1}} \right)^{\delta_F} - \frac{\varepsilon}{\varepsilon-1} P_{F,t+k} \Psi_{t+k} \right] \right\} = 0 \tag{3.21}$$

In setting the new price for imports, domestic retailers are concerned with the future path of import inflation as well as the LOP gap, Ψ_t. Essentially, Ψ_t is the margin over and above the wholesale import price. A non-zero LOP gap represents a wedge between the *world* and domestic import prices. This provides a mechanism for incomplete import pass-through

[9]Details are shown in Appendix (3.A.1) .

in the short-run, implying changes in world import prices have a gradual effect on the domestic economy. Similarly, the import price inflation dynamic can be shown to follow the following NKPC:

$$\pi_{F,t} = \frac{1}{1+\beta\delta_F}\left(\beta E_t \pi_{F,t+1} + \delta_F \pi_{F,t-1} + \lambda_F \psi_t\right) \tag{3.22}$$

where $\lambda_F = \frac{(1-\beta\theta_F)(1-\theta_F)}{\theta_F}$. Log-linearizing the definition of CPI and taking the first difference yields the following relationship for overall inflation:

$$\pi_t = (1-\alpha)\pi_H + \alpha\pi_F \tag{3.23}$$

Taking the definition for overall inflation (3.23) together with equations (3.19) and (3.22) completes the specification of inflation dynamics for the SOE.

3.2.4 Equilibrium

3.2.4.1 Aggregate demand and output

Goods market clearing in the domestic economy requires that domestic output is equal to the sum of domestic consumption and foreign consumption of home produced goods (exports):

$$y_t = c_{H,t} + c^*_{H,t} \tag{3.24}$$

The optimal demand functions for $C_{H,t}$ and $C^*_{H,t}$ are given by:

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \quad \text{and} \quad C^*_{H,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C^*_t \tag{3.25}$$

and taking the log of the two demand functions and using the definitions of the log of TOT (s_t) and the log of the LOP gap (ψ_t) gives:

$$c_{H,t} = (1-\alpha)[\alpha\eta s_t + c_t] \tag{3.26}$$

$$c^*_{H,t} = \alpha[\eta(s_t + \psi_t) + c^*_t] \tag{3.27}$$

From equation (3.26), an increase in s_t (equivalent to an increase in domestic competitiveness in the world market) will see domestic agents substitute out of foreign-produced goods into home-produced goods for a given level of consumption. The magnitude of substitution will depend on η, the elasticity of substitution between foreign and domestic goods; and the degree of openness, α. Similarly, from equation (3.27) an increase in s_t will see foreigners substitute out of foreign goods and consume more home goods for a given level of income.

Substituting equations (3.26) and (3.27) into (3.24) yields the goods market clearing condition for the SOE as:

$$y_t = (1-\alpha)c_t + \alpha c_t^* + (2-\alpha)\alpha\eta s_t + \alpha\eta\psi_t \tag{3.28}$$

Notice that when $\alpha = 0$, the closed economy case, it gives $y_t = c_t$.

3.2.5 The monetary policy reaction function

In order to estimate the deep structural parameters, the behavior of the domestic monetary authority is specified to complete the small open economy model. The aim of the monetary authority is to stabilize both output and inflation according to a simple Taylor type rule such that:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\phi_1\pi_t + \phi_2\Delta y_t] \tag{3.29}$$

where ρ_r is the degree of interest rate smoothing, ϕ_1 and ϕ_2 are the relative weights on inflation and output growth respectively. The approach here follows Orphanides (2003) in including output growth rather than the traditional output gap measure in the Taylor rule to provide a historical view on the central bank's behavior over the sampling period.

3.2.6 The linearized model

This subsection summarizes the complete log-linearized model. Log-linearizing the intertemporal Euler equation (3.5) gives the following dynamic equation relating past, current and future consumption with the real interest rate:

$$c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \frac{1-h}{\sigma}(r_t - E_t\pi_{t+1}) \tag{3.30}$$

Using the model's definition for the terms of trade, the terms of trade growth can be rewritten as:

$$\Delta s_t = \pi_{F,t} - \pi_{H,t} + \nu_t^s \tag{3.31}$$

where ν_t^s represents the measurement error from the model's definition. The assumption of perfect capital mobility and complete international markets gives the usual UIP condition (3.11) plus a risk premium term (ν_t^q) as:

$$\Delta E_t q_{t+1} = -\{(r_t - E_t \pi_{t+1}) - (r_t^* - E_t \pi_{t+1}^*)\} + \nu_t^q \tag{3.32}$$

In addition to the UIP condition, domestic consumption is tied with foreign consumption through the international risk sharing condition in equation (3.9) as:

$$c_t - hc_{t-1} = y_t^* - hy_{t-1}^* - \frac{1-h}{\sigma} q_t \tag{3.33}$$

The dynamic behavior of domestic inflation can be summarized using a Phillips curve under the assumption of monopolistic producers together with the Calvo pricing mechanism as:

$$\pi_{H,t} = \frac{1}{1+\beta\delta_H}\Big(\beta E_t \pi_{H,t+1} + \delta_H \pi_{H,t-1} + \lambda_H mc_t\Big) + \nu_t^{\pi_H} \tag{3.34}$$

where $mc_t = \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \varphi y_t + \alpha s_t - (1+\varphi)a_t$ is the log of the marginal cost, and $\nu_t^{\pi_H}$ is the measurement error of the domestic inflation Phillips curve. The assumption of monopolistic importers gives a similar Phillips curve describing the behavior of import inflation:

$$\pi_{F,t} = \frac{1}{1+\beta\delta_F}\Big(\beta E_t \pi_{F,t+1} + \delta_F \pi_{F,t-1} + \lambda_F \psi_t\Big) + \nu_t^{\pi_F} \tag{3.35}$$

where $\psi_t = -[q_t + (1-\alpha)s_t]$ is the log of LOP gap that gives rise to imperfect exchange rate pass-through, and $\nu_t^{\pi_F}$ is the measurement error of the import inflation Phillips curve. From the definition of the CPI, overall inflation can be written as:

$$\pi_t = (1-\alpha)\pi_{H,t} + \alpha\pi_{F,t} \tag{3.36}$$

The goods market clearing condition requires that domestic output is equal to the sum of domestic consumption plus exports gives:

$$y_t = (2-\alpha)\alpha\eta s_t + (1-\alpha)c_t + \alpha\eta\psi_t + \alpha y_t^* \tag{3.37}$$

The behavior of the central bank is described using a Taylor type reaction function:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)(\phi_1 \pi_t + \phi_2 \Delta y_t) + \nu_t^r \tag{3.38}$$

where ν_t^r is the measurement error to the policy maker's reaction function. To complete the linearized model, three exogenous AR(1) driving processes are included for a_t, y_t^* and $r_t^* - \pi_t^*$ with AR(1) coefficients ρ_a, ρ_{y^*} and ρ_{r^*} respectively.

3.3 Empirical analysis

This section outlines the procedure used to obtain the posterior distribution of the structural parameters underlying the model described in section (3.2).

3.3.1 The Bayesian approach

Fernandez-Villaverde and Rubio-Ramirez (2004) showed the Bayesian estimator is consistent in large samples such that the posterior distribution of the parameters collapses to its pseudotrue values. The use of prior, $p(\Theta)$, allows researchers to include information about the possible values of parameters that are considered to be outside the formal modeling framework. Adding $\ln p(\Theta)$ smoothes the often uneven surface of the log likelihood function making estimation algorithms much easier. However, a tightly specified prior can give the illusion that the econometrician has collected useful evidence, i.e.: a relatively small standard error for the estimated coefficient.[10] This paper takes an agnostic approach where the prior specifications are relatively diffuse.

In the Bayesian context, all inference about the parameter Θ is contained in the posterior distribution. The posterior density of the model parameter θ can be written as:

$$p(\Theta|Y^T) = \frac{L(Y^T|\Theta)p(\Theta)}{\int L(Y^T|\Theta)p(\Theta)d\Theta} \tag{3.39}$$

where $p(\Theta)$ is the prior density and $L(Y^T|\Theta)$ is the likelihood conditional on the observed data Y^T. The likelihood function can be computed via the state-space representation of the model together with the measurement equation linking the observed data to the state vector. The solution of the linearized economic model described in section (3.2.6) has the following state-space representation:

$$X_{t+1} = \Gamma_1 X_t + \Gamma_2 w_{t+1} \tag{3.40}$$

$$Y_t = \Lambda X_t + \mu_t \tag{3.41}$$

[10]The problem is more severe if the likelihood function has little information.

where X_t is the state vector, Y_t is the vector observed variables, ϵ_t is the vector of state innovations, μ_t is the measurement error, Γ_1 and Γ_2 are the solution matrices of the rational expectations model, and Λ is the matrix defining the relationship between the state vector and the observed variables. Assuming the state innovations and measurement errors are normally distributed with mean zero and variance-covariance matrices Ξ and Υ respectively, the likelihood function of the model is given by:

$$\ln L(Y^T|\Gamma_1,\Gamma_2,\Lambda,\Xi,\Upsilon) = -\frac{TN}{2}\ln 2\pi - \sum_{t-1}^{T}\left[\frac{1}{2}\ln|\Omega_{t|t-1}| + \frac{1}{2}\mu_t'\Omega_{t|t-1}^{-1}\mu_t\right] \tag{3.42}$$

where $\Theta = \{\Gamma_1,\Gamma_2,\Lambda,\Xi,\Upsilon\}$, $\Omega_{t|t-1} = \Lambda'\Sigma_{t|t-1}\Lambda + \Upsilon$ and $\Sigma_{t|t-1} = \Gamma_1\Sigma_{t-1|t-1}\Gamma_1' + \Gamma_2\Xi\Gamma_2'$. Given some initial state value, $S_0 \sim N(\bar{S}_0, \Sigma_0)$, the likelihood function (3.42) can be evaluated using the Kalman filter algorithm described in Anderson et al. (1996). Recognizing that $\int L(Y^T|\theta)p(\theta)d\theta$ is a constant, it is only necessary to be able to evaluate the posterior density up to a proportionate constant using the following relationship:

$$p(\Theta|Y^T) \propto L(Y^T|\Theta)p(\Theta) \tag{3.43}$$

The posterior density summarizes the information contained in the likelihood function weighted by the prior density $p(\Theta)$. The prior can be used to bear information not contained in the sample, Y^T. The random walk Metropolis-Hastings algorithm described in An and Schorfheide (2007) is used to simulate the Markov Chain Monte Carlo (MCMC) draws to construct the posterior distribution of the model's parameters.

3.3.2 Data and priors

New Zealand data from 1990Q1 to 2006Q4 is used to estimate the model. Quarterly observations on log of domestic output (y_t), interest rates (r_t), overall inflation(π_t), import inflation ($\pi_{F,t}$), log of real exchange rate (q_t), the log of terms of trade (s_t), log of foreign output (y_t^*), and foreign real interest rate ($\bar{r}_t^* = r_t^* - \pi_t^*$) are taken from Statistics New Zealand and the RBNZ database. All variables are re-scaled to have a mean of zero and could be interpreted as an approximate percentage deviation from the mean.[11] See Appendix (3.A.2) for a more detailed description of the data transformations.

The choice of priors for the estimation are guided by several considerations. At the basic

[11] Apart from the interest rate and inflation data which are already in percentage terms.

level, the priors reflect the modeler's beliefs and confidence about the likely location of the structural parameters. Information on the structural characteristics of the New Zealand economy, such as the degree of openness, being a commodity producer and its institutional settings, were all taken into account. In the case of New Zealand, micro-level studies are relatively scarce. Priors from similar studies using New Zealand data, for example Justiniano and Preston (2004), and Lubik and Schorfheide (2007) , were also considered. Finally, the choice of prior distributions reflects restrictions on the parameters such as non-negativity or interval restrictions. Beta distributions were chosen for parameters that are constrained on the unit-interval. Gamma and normal distributions were selected for parameters in $\Re^+$, while the inverse gamma distribution was used for the variance of the shocks.

The priors on the model's parameters are assumed to be independent of each other, which allows for easier construction of the joint prior density used in the MCMC algorithm. Furthermore, the parameter space is truncated to avoid indeterminacy or non-uniqueness in the model's solution.[12] The marginal prior distributions for the model's parameters are summarized in Table (3.1).

3.3.3 Estimation and convergence diagnostics

Given the data and prior specifications in section (3.3.2), two parallel 2 million draws of the Markov chain were generated.[13] The Markov chains are generated conditional on the degree of openness (α) and the time preference (β) parameters, which are fixed at 0.3 and 0.99 respectively. $\alpha = 0.3$ coincides with the proportion of imported goods in the CPI basket over the sample period and $\beta = 0.99$ corresponds with an annual risk free rate of 4 percent.

Various convergence diagnostic statistics were computed after an initial 75% burn-in period. The aim is to assess whether the sequence of Markov chain draws has converged to the target distribution to ensure the reliability of the estimates generated from the Metropolis Hastings algorithm. The first column of Table (3.2) shows the mean of the posterior distribution. The NSE refers to the Numeric Standard Error as an approximation to the true posterior standard error and the p-value is the test between the means generated from the two independent chains as in Geweke (1999). For each of the parameter estimates, there is no indication the two means generated from the two chains are significantly different

[12]This only accounts for a very small proportion of the draws, around 0.2%.

[13]Each chain is generated at different starting values. It takes approximately 25 CPU hours to generate each independent chain using the APAC linux cluster machine.

from each other. The seventh column shows the univariate "shrink factor" using the ratio of between and within variances as in Brooks and Gelman (1998). A shrink factor close to 1 is evidence for convergence to a stationary distribution. All MCMC diagnostic tests suggest that the Markov chains have converged to the stationary distribution after 2 million iterations.[14]

3.4 Posterior parameter estimates

Based on the two independent Markov Chains, the posterior mean and the 95 percent probability intervals are computed for each of the parameters, with results reported in Table (3.2). The prior and estimated posterior marginal densities are plotted in Figure (3.1). The plots indicate there is a substantial amount of information contained in the data to help update the prior beliefs on the model's parameters. The posterior marginal densities are noticeably more concentrated relative to the prior densities.

The results indicate there is a relatively high degree of habit persistence, with $h = 0.94$, compared to other studies for the U.S. and the Euro area, eg: Smets and Wouters (2003) and Lubik and Schorfheide (2005).[15] The high degree of habit formation limits the elasticity of consumption with respect to real interest rate changes, while the impact from consumption on domestic inflation is much stronger. The inverse elasticity of intertemporal substitution, σ, is estimated to be 1.20. The estimate is very close to the prior value of 1 and similar to the results obtained by Justiniano and Preston (2004). The elasticity of substitution between home and foreign goods, η, is around 1.02. The unitary elasticity is in line with the prior that New Zealand is a small open commodity-producer and its consumption basket relies heavily on foreign produced goods. The estimated inverse elasticity of substitution for labor, $\varphi = 0.62$, turns out to be less than 1. This means a 1 percent increase in the real wage will result in more than a 1 percent increase in the labor supply.

On the production side, the probability of not changing prices in a given quarter is estimated to be around 93 percent for domestic firms and lower for import retailers at 77 percent. The estimated Calvo coefficients imply the average duration of price contracts is around twelve quarters for domestic firms and four quarters for import retailers (degree of

[14]The number of iterations required to guarantee convergence is much larger than those often reported in the literature.

[15]All the results reported here are based on the mean of the posterior distribution.

incomplete pass-through).[16] The degree of home price stickiness is much greater than those reported for the Euro area and the U.S., whereas, the degree of import price stickiness is inline with previous empirical estimates. On the other hand, the degree of price indexation is estimated to be 0.58 for domestic firms and 0.46 for import retailers. Together, the Phillips Curves estimates imply there is a greater amount of stickiness in the price setting behavior of domestic firms relative to import retailers where they face stronger competition. This in turn implies greater persistence in the dynamics of domestic inflation relative to import inflation.

The simple reaction function used in the model provides a fairly good description of monetary policy over the stable inflation period in New Zealand. The posterior median for the degree of interest rate smoothing is estimated to be 0.78 with 1.25 and 0.50 being the weight on inflation and output respectively. The results obtained here are consistent with empirical estimates of Taylor rule coefficients in Plantier and Scrimgeour (2002).

The last column (flat prior) of Table (3.2) reports the mean of the Markov Chain draws with a non-informative prior. The mean of the parameters does not change significantly compared to the model estimated with informative priors.[17] However, there are a few exceptions, the mean of the non-informative estimate falls outside the informative estimate's 95 percent probability interval. The elastic of substitution between home and foreign goods (η) is slightly lower at 0.81 compared to 1.02. This suggests New Zealand's small open economy characteristic is more pronounced with limited substitutability between its production and consumption basket of goods. The inverse elasticity of labour supply (φ) also turns out to be smaller compared with the informative estimate, suggesting an even more elastic labor supply. The stickiness parameter for import prices (θ_F) is estimated to be slightly larger at 0.83. However, the conclusion that domestic prices are observed to be much more sticky still holds. Finally, the response of the interest rate to output (ϕ_2) in the reaction function is slightly lower, though this coefficient will not significantly affect the optimal policy simulation results presented here. Overall, the Bayesian estimator seems robust to the prior specification.

[16] Duration $= \frac{1}{1-\theta_i}$.

[17] The flat prior estimates are still subject to the same interval constraints.

3.5 Stabilization bias for a small open economy

It is well recognized that commitment policy will produce a universally superior inflation outcome compared with the discretionary equilibrium due to the time-inconsistency problem advocated by Kydland and Prescott (1977), Barro and Gordon (1983), and Svensson (1997). The analysis here tries to quantify the size of the stabilization bias for a SOE using the model described in section (3.2) and parameters estimated in section (3.4) for New Zealand.

For a very small class of models, a closed form representation of the model's theoretically consistent social welfare function can be derived from taking the second order approximation of the representative household's discounted life-time utility, see Erceg et al. (2000) and Woodford (2002) for example. However, this approach is only feasible for a small subset of models or as a special case by restricting the model's parameters.[18] As an alternative, it is commonly accepted in the literature and among policy makers that monetary policy should be aimed at stabilizing inflation and some measure of real activity. In the case of New Zealand, the policy objectives are explicitly set out in the Policy Target Agreement (PTA) between the Bank and the Minister of Finance.

> *"In pursuing its price stability objective, the Bank shall implement monetary policy in a sustainable, consistent, and transparent manner and shall seek to avoid unnecessary instability in output, interest rates and the exchange rate."*[19]

Here, the social objective function is set up to be consistent with the PTA agreement, one that penalizes squared deviations in inflation from target, squared deviation in output from potential, squared deviation in the exchange rate and an interest rate smoothing term. The interest rate smoothing term ensures policy changes in response to shocks occur in small steps. Sack and Wieland (2000) argues that including the interest rate smoothing term may in fact be optimal even though the central bank's main objective is to replicate the second best outcome due to data and parameter uncertainty. Following the literature, the social objective function is approximated using the following linear quadratic loss function:

$$L(t,\infty) = E_t \sum_{j=0}^{\infty} \delta^j \left[\pi_{a,t+j}^2 + \lambda y_{t+j}^2 + \varsigma q_{t+j}^2 + \nu \Delta r_{t+j}^2\right] \tag{3.44}$$

[18] Gali and Monacelli (2005) derived the social welfare function using the second order approximation of the household's utility by setting $\sigma = \eta = \varphi = 1$.

[19] Extract from Section 4(c) of the PTA aggrement, 1999, available on the RBNZ website: http://www.rbnz.govt.nz/monpol/pta/.

where $\pi_{a,t}$ is annualized inflation, y_t is output, q_t is the real exchange rate and Δr_t is the change in the nominal interest rate; and λ, ς and ν are the weights relative to inflation. All variables are written as deviations from its steady state.

Under optimal commitment policy, the central bank optimizes once at $t = 0$ by minimizing the loss function given in equation (3.44) subject to the dynamic constraints of the economy, and permanently commits to the optimal plan. In this case, the dynamic equilibria of the economy will be augmented to reflect the commitment made earlier by the central bank.[20] Optimal discretionary policy is one where the central bank optimizes equation (3.44) on a period by period basis. The problem occurs once private agents form expectations about the future. There is then no incentive for the central bank to follow through with earlier policy announcements – the classic time-inconsistency problem. The dynamic behavior of the economy under discretion constitutes a Stackelberg-Nash equilibria in which policymakers optimizing today are the Stackelberg leaders, and private agents and future policymakers are Stackelberg followers. The algorithms described in Dennis (2007) are used to solve the commitment and discretionary dynamic equilibria and the value of the loss function is calculated for each case.

To define a common metric for the size of the stabilization bias, Dennis and Soderstrom (2006) use the permanent deviation of inflation from target that is equivalent to moving from discretionary policy to commitment. The *inflation equivalent* measure for a particular set of model parameters, Θ, is given by:

$$\hat{\pi}(\Theta) = \sqrt{L_d(\Theta) - L_c(\Theta)} \tag{3.45}$$

where $L_c(\Theta)$ and $L_d(\Theta)$ are the values of the optimized loss function for a particular set of parameters Θ under commitment and discretion respectively. Other studies also report the *percentage gain* measure relative to the commitment equilibria defined as $100\left(1 - \frac{L_c(\Theta)}{L_d(\Theta)}\right)$. The discussions here will focus on the inflation equivalent measure which is also intuitively more appealing.

3.5.1 Baseline closed economy simulation

A closed economy is one where trade (the import share $\alpha \to 0$) and financial (the exchange rate channel is turned off) linkages with the rest of the world are shut off. The model

[20] The solution of the model will include a set of dynamic lagrange multipliers.

collapses to the standard canonical closed economy representation similar to the one in Clarida et al. (2001). The aim is to isolate the open economy effects and help comparison with previous closed economy studies. The model is simulated using 10,000 parameter draws randomly selected from the stationary posterior distribution. Even though the PTA gives some guidance on the choice of target variables, their relative weights in the loss function are not explicitly specified or announced publicly. For the baseline scenario, the weights on output (λ) and interest rate smoothing (ς) are chosen to be 0.5. These weights coincide with baseline values used in Svensson (2000) and Dennis and Soderstrom (2006).

Figure (3.2) plots the empirical distribution of the estimated stabilization bias with detailed statistics reported in Table (3.3).[21] The mean of the inflation equivalent measure is calculated to be 0.65% with a standard deviation of 0.32. The estimate is comparable with the results reported in Dennis and Soderstrom (2006) using the same loss function parameters across four closed economy models (ranging between 0.15% to 1.43%) once parameter uncertainty is taken into account.

3.5.2 Size of the stabilization bias

Using the same set of baseline loss function parameters, the full open economy model is simulated to calculate the stabilization bias for the SOE. The estimated mean of the distribution is 1.24% with a standard deviation of 0.33. The standard deviation is similar to that of the closed economy while the mean is much higher. The values of the optimized loss function under both commitment and discretionary policy are higher due to the impact of international shocks. When the exchange rate is included in the loss function, even with a relatively small weight ($\nu = 0.1$), the value of the optimized loss functions are remarkably higher. This largely reflects the relatively high variance of the real exchange rate entering into the objective function, the estimated stabilization bias more than doubles to 2.75%.[22]

To help the comparison and check on the robustness of the results, five other different combinations of policy preferences are calculated with the density plots shown in Figure (3.2).[23] The size of the stabilization bias is estimated to vary between 0.82-4.16% with standard deviations between 0.23-0.57 depending on the loss function parameters. Across all loss function parameterizations, the estimated stabilization bias is much greater compared

[21] Figure (3.2) and Table (3.3) contain simulation results for other policy parameters that will be discussed later.

[22] The implication of including the exchange rate as one of the objectives will be discussed in more detail in the next sub-section.

[23] The chosen loss function parameters are by no means exhaustive, instead, these are chosen to provide a reasonable comparison with previous studies.

with the closed economy baseline simulation. Furthermore, the size of the stabilization bias in the SOE appears to be higher than the closed economy results (between 0.05-3.6%) reported in Dennis and Soderstrom (2006) across a range of loss function parameterizations.

One important observation from the simulation results is that the estimated stabilization bias for a SOE is much higher compared with the closed economy case. The conclusion is robust across different loss function parameterizations and model parameters. As the economy becomes more open, the cost of discretionary policy relative to commitment equilibrium is higher. In the closed economy, only expectations of future domestic inflation matters. In which case, the stabilization bias only relates to the tradeoffs between stabilizing domestic inflation and output in the face of cost push disturbances.

For a small open economy, the policy tradeoffs are much more complex with the presence of imperfect import price pass-through and international disturbances. First, policies that move the short-term interest rate to offset the impacts of demand or supply disturbances will also affect the exchange rate. This, in turn, affects the rate of inflation. Both output and inflation objectives cannot be achieved simultaneously resulting in a higher stabilization bias. Second, the presence of incomplete pass-through in import prices represents an additional channel for the central bank to manipulate expectations of future imported goods inflation and the exchange rate. Any attempts by the central bank to try and stabilize domestic or foreign disturbances will indirectly affect the LOP gap ($\psi_t = -[q_t + (1-\alpha)s_t]$) via exchange rate movements. In addition to the inflation-output tradeoff, the stabilization bias also includes the tradeoff between import inflation and the LOP gap.

The empirical results suggest the gains from commitment policy are remarkably higher for a SOE. The size of the stabilization bias under the baseline parameterizations is nearly twice as large for a SOE relative to that usually found for closed economies. The result offers a possible explanation for the motivation behind many SOE central banks' move towards an inflation targeting framework as a way of anchoring expectations and minimizing the discretionary bias.

3.5.3 The increasing desire for exchange rate stability

There has been increasing debate on whether SOE central banks should focus more on exchange rate stabilization. In the case of New Zealand, this desire was reflected in the updated PTA in 1999 to minimize exchange rate fluctuations in the operation and implementation of monetary policy over the business cycle. Subsequently, following several public comments by the New Zealand Finance Minister expressing discomfort over the high volatility of the New Zealand dollar, the RBNZ was granted the capacity to intervene if the foreign exchange market became "disorderly".[24] The RBNZ first publicly acknowledged the use of its new intervention capacity on 11 June 2007, it is useful to investigate how this increasing preference for minimizing exchange rate fluctuations impacts on the size of the stabilization bias. The changing policy preference may not be unique to the case of New Zealand with other SOE's such as Australia and Canada currently also facing unprecedented rises in commodity prices.

To address this important policy question, Figure (3.3) plots the estimated stabilization bias with respect to the the weights on output (λ) and exchange rate (ς) while fixing the weight on the interest rate smoothing term (ν) to be 0.5.[25] The first observation is that the size of the stabilization bias is a non-decreasing function with respect to the weight placed on output for a given weight on the exchange rate. This essentially replicates the well documented closed economy result, where discretion policy will result in inflation variability being too high, and output variability too low, relative to the commitment equilibrium. The higher preference for output stability in the face of cost push shocks will induce greater incentive for the central bank to manipulate private agent's expectations, increasing the size of the stabilization bias.

The second observation is that for a given weight on output, the stabilization bias is a monotonic increasing function with respect to the weight placed on the exchange rate. This offers some interesting insights into the operation of monetary policy for a SOE. Under commitment, the central bank trades off some volatility in the output gap in order to achieve greater stability in domestic inflation and the LOP gap, hence indirectly lowering the variability of the exchange rate.[26] Monacelli (2005) found similar results looking at productivity shocks only. The intuition is that commitment policy helps anchor inflation expectations, therefore resulting in more stable inflation accompanied with less frequent changes to the interest rate. This in turn translates into more stable exchange rate fluctuations via the UIP in equation (3.11) for a given level of risk premium shock. Higher preference for lower exchange rate fluctuations is equivalent to placing more weight on in-

[24]See RBNZ press release on 30th March 2004, `http://www.rbnz.govt.nz/news/2004/0148546.html`.

[25]The simulation results are generated using the mean of the posterior distribution of the model's structural parameters.

[26] Detailed simulation results of the unconditional variance of the state variables are available from the author upon request.

flation variability. However, this will induce greater fluctuations in output relative to the discretion outcome, hence increasing the size of the stabilization bias.

An important policy implication is that a higher preference for exchange rate stability will result in larger gains from commitment. The updating of the PTA to include the exchange rate as one of the policy objectives essentially requires the RBNZ to implement monetary policy in a more time-consistent manner. The ability of the central bank to fully commit to preannounced policies is viewed as a much more important mechanism in achieving a more stable exchange rate along side of its other policy objectives.

3.5.4 Robustness analysis

One of the crucial assumptions underlying the set of estimated parameters is the detrending method used to extract the cyclical component of the output data. Canova (1998) emphasized different detrending methods can imply quite different business cycle dynamics and therefore affects the set of estimated parameters underlying the model. Cho and Moreno (2006) highlighted the coefficients on the real interest rate in the IS curve, and the marginal cost in the Phillips Curve are particularly sensitive to different detrending methods employed. The former parameter governs the transmission mechanism of monetary policy on consumption while the latter relates to the tradeoff between inflation and output. Both of these parameters are crucial to the optimal policy analysis presented here. To assess the robustness of the conclusions highlighted above with respect to the different data treatments, the model outlined in (3.2) is re-estimated using different detrending methods (linear and quadratic trend) for domestic and foreign output.[27]

The estimation results confirms Cho and Moreno's (2006) previous analysis. One advantage of using a micro-founded model is that it allows one to uncover which "deep" parameters are particularly sensitive to the different detrending methods.[28] Two parameters were identified, the elasticities of intertemporal substitution (σ) and labour supply (φ). σ relates to the elasticity of consumption with respect to changes in the real interest rate, while φ relates to the tradeoff between output and domestic inflation in the Phillips Curve. The mean of σ is estimated to be 1.19, 1.27 and 0.84 for the HP, linear and quadratic trend respectively. While the linear trend estimate falls within the HP trend's 95% probability interval, the quadratic trend estimate is statistically smaller. On the other hand, the mean

[27]Detailed statistics of the estimation results are available upon request.

[28]In Cho and Moreno (2006), the parameters in front of the real interest rate and marginal cost in the IS and Phillips curves are combinations of the "deep" parameters.

estimate of φ for the HP and linear trend is very similar, around 0.62 and 0.60 respectively, while the quadratic trend is slightly higher around 0.76. The price stickiness parameters, θ_H and θ_F which also relates to the degree of tradeoff between inflation and output is observed to be fairly robust across the different detrending methods. The same applies to the rest of the parameter estimates underlying the model.

Despite some small differences in some of the key parameters underlying the model, the general conclusion highlighted in sections (3.5.2) and (3.5.3) holds across the different detrending methods. For the baseline loss function parameterizations, the estimated size of the stabilization bias for the SOE is still more than double that of the closed economy, 0.92% relative to 0.40% using a linear trend, and 1.27% relative to 0.63% using a quadratic trend. Simulation results continue to show a monotonically increasing relationship between the weight on the exchange rate and the size of the stabilization bias.

3.6 Concluding remarks

This paper develops an empirical model to investigate the degree of inefficiencies arising from discretionary policy relative to the commitment equilibrium. Much of the discussion is devoted to analyzing the policy tradeoffs faced by the central bank within a SOE, and how that differs from a closed economy. Two key results emerge from the analysis. First, the estimated size of the stabilization bias for a SOE is found to be nearly twice as large relative to that usually found in the closed economy counterpart. The result is robust across different loss function parameterizations and model parameters. As the economy becomes more open, the cost of discretionary policy relative to commitment equilibrium is higher. Second, the size of the stabilization bias increases with the policymaker's preference for stabilizing exchange rate fluctuations. This implies that a stronger attitude towards pre-commitment of policy will help minimize the inefficiency arising from the stabilization bias when the exchange rate is included as one of the stabilization objectives.

Two parameters, the elasticities of intertemporal substitution and labour supply, were identified to be particularly sensitive to the different data treatments. Both parameters, which relate to the elasticity of consumption with respect to changes in the real interest rate and the tradeoff between output and domestic inflation in the Phillips Curve, are crucial to the analysis presented here. Despite some small differences in these parameters, the key insights highlighted in the paper hold across different detrending methods.

The analysis was restricted to a relatively simple specification of the model with only two sources of nominal rigidities, and a linear production function in labor. However, the results suggests that it would be worthwhile expanding the analysis to incorporate other factors influencing the size of the stabilization bias from pre-commitment, including: (i) capital accumulation and investment rigidities; (ii) labour market rigidities; and (iii) explicit optimizing behavior of the central bank in estimating the model. In addition, the key results and policy implications highlighted rests on the assumption of UIP. While the UIP hypothesis is an ongoing debate in the literature, it would be useful to relax this assumption in future work.

Table 3.1: Prior distributions statistics

Parameter	Domain	Density	Mean	Std dev.	2.5%	97.5%
h	[0, 1]	Beta	0.500	0.200	0.128	0.871
σ	$\Re^+$	Normal	1.000	0.400	0.376	1.923
η	$\Re^+$	Gamma	1.000	0.400	0.375	1.922
φ	$\Re^+$	Gamma	1.000	0.400	0.377	1.917
θ_H	[0, 1]	Beta	0.500	0.150	0.214	0.787
θ_F	[0, 1]	Beta	0.500	0.150	0.213	0.786
δ_H	[0, 1]	Beta	0.500	0.200	0.128	0.871
δ_F	[0, 1]	Beta	0.500	0.200	0.132	0.870
ϕ_1	$\Re^+$	Gamma	1.500	0.250	1.050	2.031
ϕ_2	$\Re^+$	Gamma	0.250	0.100	0.094	0.479
ρ_r	[0, 1]	Beta	0.500	0.200	0.128	0.871
ρ_{r*}	[0, 1]	Beta	0.500	0.200	0.129	0.871
ρ_a	[0, 1]	Beta	0.500	0.200	0.127	0.869
ρ_{y*}	[0, 1]	Beta	0.500	0.200	0.129	0.872
σ_a	$\Re^+$	InvGamma	1.000	0.300	0.598	2.000
σ_s	$\Re^+$	InvGamma	1.000	0.300	0.597	1.997
σ_q	$\Re^+$	InvGamma	1.000	0.300	0.598	1.988
σ_{π_H}	$\Re^+$	InvGamma	1.000	0.300	0.602	1.989
σ_{π_F}	$\Re^+$	InvGamma	1.000	0.300	0.600	2.000
σ_r	$\Re^+$	InvGamma	1.000	0.300	0.600	1.997
σ_{y^*}	$\Re^+$	InvGamma	1.000	0.300	0.597	1.991
σ_{r^*}	$\Re^+$	InvGamma	1.000	0.300	0.601	1.997

Table 3.2: Posterior estimates and MCMC diagnostic statistics

parameters	Post Mean	Post Std	2.5%	97.5%	NSE	p-value	B-G	Flat prior
h	0.937	0.011	0.914	0.955	0.001	0.254	1.042	0.953
σ	1.195	0.097	1.012	1.396	0.010	0.113	1.122	1.101
η	1.016	0.049	0.918	1.102	0.009	0.106	1.124	0.811
φ	0.620	0.079	0.483	0.779	0.013	0.501	1.021	0.442
θ_H	0.927	0.021	0.884	0.967	0.003	0.554	1.013	0.950
θ_F	0.771	0.021	0.731	0.807	0.003	0.332	1.030	0.832
δ_H	0.581	0.053	0.458	0.683	0.008	0.413	1.030	0.648
δ_F	0.460	0.030	0.399	0.517	0.004	0.065	1.125	0.440
ϕ_1	1.247	0.102	1.051	1.483	0.017	0.722	1.006	1.112
ϕ_2	0.498	0.025	0.448	0.537	0.004	0.052	1.182	0.414
ρ_r	0.775	0.028	0.722	0.831	0.004	0.228	1.057	0.775
ρ_{r^*}	0.819	0.018	0.779	0.855	0.002	0.374	1.020	0.833
ρ_a	0.891	0.015	0.861	0.919	0.002	0.210	1.041	0.910
ρ_{y^*}	0.812	0.030	0.757	0.865	0.005	0.412	1.026	0.818
σ_a	0.900	0.097	0.676	1.041	0.014	0.064	1.147	0.964
σ_s	3.633	0.178	3.342	3.995	0.028	0.051	1.151	4.062
σ_q	6.171	0.163	5.874	6.495	0.026	0.237	1.056	6.510
σ_{π_H}	1.219	0.068	1.074	1.347	0.010	0.087	1.122	1.079
σ_{π_F}	2.540	0.190	2.096	2.842	0.024	0.547	1.018	2.401
σ_r	0.799	0.054	0.702	0.901	0.009	0.616	1.012	0.802
σ_{y^*}	0.480	0.044	0.407	0.569	0.007	0.700	1.006	0.459
σ_{r^*}	0.638	0.052	0.561	0.748	0.009	0.597	1.013	0.599
Log marginal likelihood	-1072.5							-1053.9

1. The parameters α and β were fixed at 0.3 and 0.99 respectively.
2. Posterior statistics are computed after 75% burn in, the acceptance rate for both of the Markov chains was around 20%.
3. NSE is the Numeric Standard Error as defined in Geweke (1999) .
4. The P-Value refers to test of two means generated from two independent chains, the test statistics is computed with $L = 0.08$, see Geweke (1999).
5. B-G is the univariate "shrink factor" for monitoring the between and within chain variance, see Brooks and Gelman (1998).

Table 3.3: Estimated stabilization bias from commitment policy

λ	ν	ς	Loss		Percent	Inflation	Prob interval		Std
y_t^2	$(\Delta r_t)^2$	q_t^2	Commit.	Discretion	gain	equiv.	2.5%	97.5%	dev
Closed economy			2.90	3.42	13.81	0.65	0.16	1.32	0.32
0.5	0.5	0.0	4.20	5.85	26.63	1.24	0.84	2.01	0.33
0.5	0.5	0.1	19.82	27.50	27.70	2.75	2.28	3.51	0.30
1.0	1.0	0.0	5.57	7.47	25.03	1.36	1.09	1.93	0.23
1.0	1.0	0.1	16.81	26.10	35.21	3.03	2.46	3.90	0.35
1.0	1.0	0.2	30.81	48.42	35.84	4.16	3.21	5.51	0.57
0.0	1.0	0.0	0.58	3.16	78.55	1.56	0.86	2.22	0.38
1.0	0.0	0.0	3.38	4.23	16.29	0.82	0.22	1.67	0.41

1. The closed economy is simulated in the absence of international shocks and the exchange rate.
2. The percentage gain measure is calculated by $\left(1 - \frac{L_c(\Theta)}{L_d(\Theta)}\right) 100$.
3. The inflation equivalent measure is calculated by $\sqrt{L_d(\Theta) - L_c(\Theta)}$.

Table 3.4: Posterior parameter estimates across different detrending assumptions

parameters	Hodrick Prescott (95% interval)	Linear (95% interval)	Quadtratic (95% interval)
h	0.94 [0.91, 0.95]	0.92 [0.90, 0.94]	0.95 [0.93, 0.96]
σ	1.19 [1.01, 1.40]	1.27 [1.13, 1.47]	0.84 [0.76, 0.96]
η	1.02 [0.92, 1.10]	0.93 [0.85, 0.99]	0.92 [0.86, 0.98]
φ	0.62 [0.48, 0.78]	0.60 [0.47, 0.78]	0.76 [0.62, 0.97]
θ_H	0.93 [0.88, 0.97]	0.94 [0.90, 0.97]	0.93 [0.88, 0.97]
θ_F	0.77 [0.73, 0.81]	0.78 [0.73, 0.83]	0.76 [0.71, 0.80]
δ_H	0.58 [0.46, 0.68]	0.54 [0.44, 0.62]	0.52 [0.44, 0.61]
δ_F	0.46 [0.40, 0.52]	0.44 [0.39, 0.48]	0.37 [0.30, 0.44]
ϕ_1	1.25 [1.05, 1.48]	1.26 [1.12, 1.44]	1.28 [1.14, 1.47]
ϕ_2	0.50 [0.45, 0.54]	0.36 [0.32, 0.41]	0.48 [0.43, 0.53]
ρ_r	0.77 [0.72, 0.83]	0.79 [0.75, 0.84]	0.77 [0.73, 0.82]
ρ_{r^*}	0.82 [0.78, 0.86]	0.81 [0.77, 0.84]	0.82 [0.78, 0.85]
ρ_a	0.89 [0.86, 0.92]	0.88 [0.85, 0.90]	0.89 [0.86, 0.92]
ρ_{y^*}	0.81 [0.76, 0.87]	0.82 [0.78, 0.86]	0.80 [0.72, 0.87]
σ_a	0.90 [0.68, 1.04]	0.91 [0.77, 1.03]	1.03 [0.88, 1.19]
σ_s	3.63 [3.34, 3.99]	3.79 [3.47, 4.07]	3.82 [3.50, 4.21]
σ_q	6.17 [5.87, 6.49]	7.17 [6.87, 7.58]	6.31 [5.98, 6.62]
σ_{π_H}	1.22 [1.07, 1.35]	1.15 [1.05, 1.23]	1.16 [1.03, 1.31]
σ_{π_F}	2.54 [2.10, 2.84]	2.21 [1.92, 2.49]	2.50 [2.01, 2.86]
σ_r	0.80 [0.70, 0.90]	0.82 [0.72, 0.91]	0.78 [0.70, 0.85]
σ_{y^*}	0.48 [0.41, 0.57]	0.52 [0.44, 0.61]	0.48 [0.41, 0.56]
σ_{r^*}	0.64 [0.56, 0.75]	0.66 [0.60, 0.72]	0.65 [0.57, 0.74]

1. The parameters α and β were fixed at 0.3 and 0.99 respectively.

2. Posterior statistics are computed after 75% burn in, the acceptance rate for all the Markov chains was around 20-30%.

Figure 3.1: Posterior and prior marginal density plot

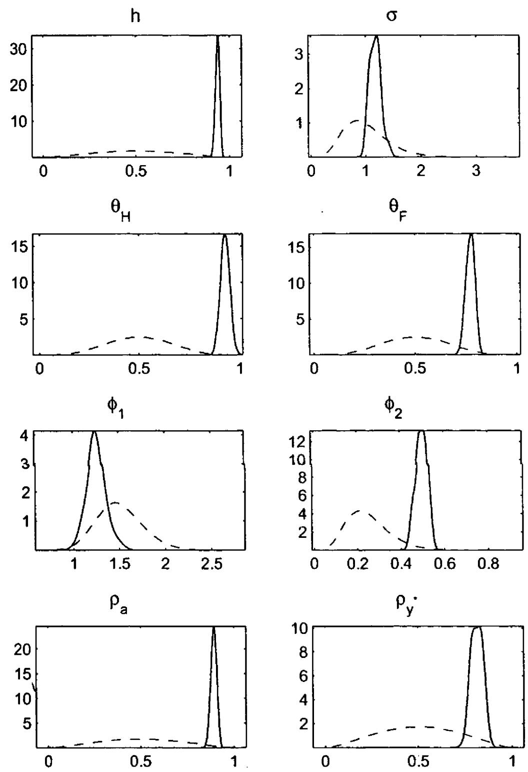


Figure 3.2: Inflation equivalent ($\hat{\pi}$) for various policy preferences

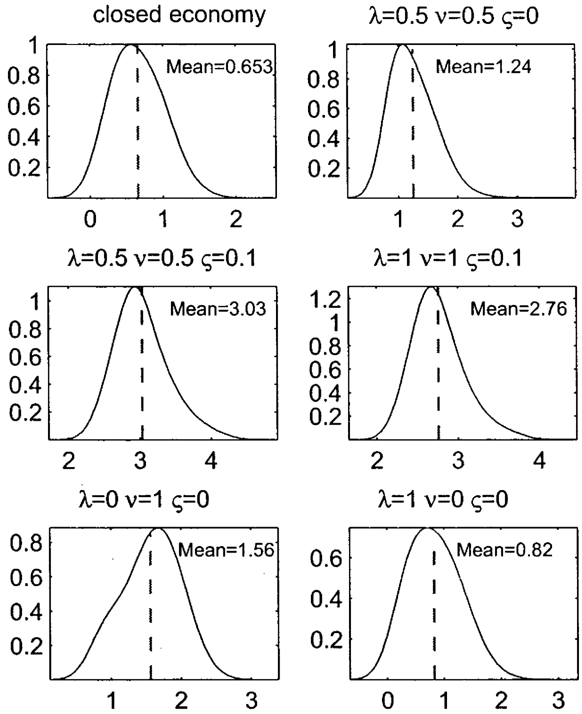
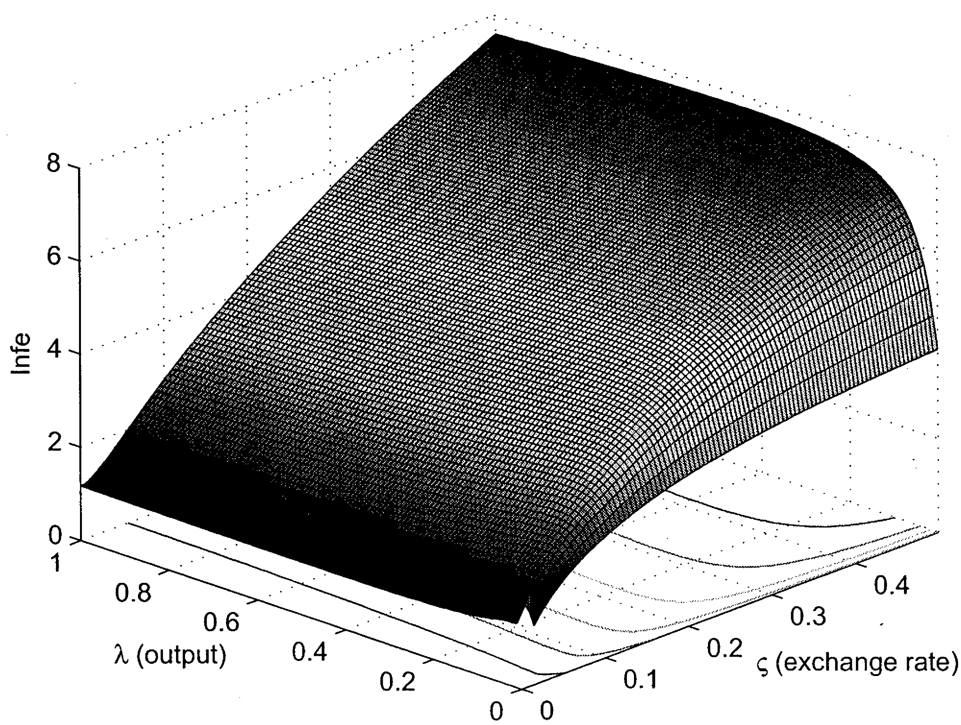


Figure 3.3: Inflation equivalent ($\hat{\pi}$) for λ and ς



3.A Appendix

3.A.1 Deriving the domestic NKPC

Rewriting the first order condition for domestic firm's pricing decision in equation (3.18):

$$\sum_{k=0}^{\infty} \theta_H^k E_t \left\{ Q_{t,t+k} Y_{t+k} \left[\bar{P}_{H,t} \left(\frac{P_{H,t+k-1}}{P_{H,t-1}} \right)^{\delta_H} - \frac{\varepsilon}{\varepsilon - 1} P_{H,t+k} MC_{t+k} \right] \right\} = 0 \tag{3.46}$$

Substitute $Q_{t,t+k} = \beta^k \left(\frac{C_{t+k}}{C_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+k}}\right)$ from the consumption Euler equation in (3.5) in equation (3.46) yields:

$$\sum_{k=0}^{\infty} (\beta\theta_H)^k P_t^{-1} C_t^{-\sigma} E_t \left\{ P_{t+k}^{-1} C_{t+k}^{-\sigma} Y_{t+k} \left[\bar{P}_{H,t} \left(\frac{P_{H,t+k-1}}{P_{H,t-1}} \right)^{\delta_H} - \frac{\varepsilon}{\varepsilon - 1} P_{H,t+k} MC_{t+k} \right] \right\} = 0 \tag{3.47}$$

Since $P_t^{-1} C_t^{-\sigma}$ is known at date t, it can be taken out of the expectation summation, after rearranging yields:

$$\sum_{k=0}^{\infty} (\beta\theta_H)^k E_t \left\{ P_{t+k}^{-1} C_{t+k}^{-\sigma} Y_{t+k} \left[\bar{P}_{H,t} \left(\frac{P_{H,t+k-1}}{P_{H,t-1}} \right)^{\delta_H} - \frac{\varepsilon}{\varepsilon - 1} MC_{t+k} P_{H,t+k} \right] \right\} = 0 \tag{3.48}$$

Log-linearizing equation (3.48) around the zero inflation steady state to obtain the decision rule for $\bar{p}_{H,t}$ gives:

$$\begin{aligned}
\bar{p}_{H,t} - \delta_H p_{H,t-1} &\approx (1 - \beta\theta_H) E_t \sum_{k=0}^{\infty} (\beta\theta_H)^k \left[p_{H,t+k} - \delta_H p_{H,t+k-1} + mc_{t+k} \right] \\
&= (1 - \beta\theta_H) \left[p_{H,t} - \delta_H p_{H,t-1} + mc_t \right] \\
&\quad + \beta\theta_H (1 - \beta\theta_H) E_t \sum_{k=0}^{\infty} \beta\theta_H \left[p_{H,t+k+1} - \delta_H p_{H,t+k} + mc_{t+k+1} \right]
\end{aligned} \tag{3.49}$$

Recognizing the last term in equation (3.49) is equal to $\beta\theta_H[\bar{p}_{H,t+1} - \delta_H p_{H,t}]$, the expression can be rewritten as:

$$\bar{p}_{H,t} - \delta_H p_{H,t-1} \approx (1 - \beta\theta_H) \left[p_{H,t} - \delta_H p_{H,t-1} + mc_t \right] + \beta\theta_H [\bar{p}_{H,t+1} - \delta_H p_{H,t}] \tag{3.50}$$

Log-linearizing the domestic aggregate price level in equation (3.16) yields:

$$\pi_{H,t} = (1 - \theta_H)(\bar{p}_{H,t} - p_{H,t-1}) + \theta_H \delta_H \pi_{H,t-1} \tag{3.51}$$

Combining equations (3.50) and (3.51) yields:

$$\pi_{H,t} - \delta_H \pi_{H,t-1} = \beta E_t(\pi_{H,t+1} - \delta_H \pi_{H,t}) + \lambda_H mc_t \tag{3.52}$$

where $\lambda_H = \frac{(1-\beta\theta_H)(1-\theta_H)}{\theta_H}$. Rearrange to obtain equation (3.22) in the text:

$$\pi_{H,t} = \frac{1}{1+\beta\delta_H}\left[\beta E_t \pi_{H,t+1} + \delta_H \pi_{H,t-1} + \lambda_H mc_t\right] \tag{3.53}$$

3.A.2 Data description

- Domestic output (y_t) is seasonally adjusted log real GDP for New Zealand detrended using the HP filter with $\lambda = 1600$.
- Overall inflation (π_t) is the annualized quarter to quarter growth rate of the consumer price index (CPI) for New Zealand.
- Import inflation ($\pi_{F,t}$) is the annualized quarter to quarter growth rate of the import deflator for New Zealand.
- Nominal interest rate (r_t) is the 90-day Bank Bill rate for New Zealand.
- Competitive price index (s_t) is the merchandize terms of trade measured "at the dock" using overseas trade statistics.
- Real exchange rate (q_t) is the log of the real exchange rate (using CPI) between New Zealand and the U.S.
- Foreign output (y_t^*) is seasonally adjusted log real GDP for the US detrended using the HP filter with $\lambda = 1600$.
- Foreign real interest rate ($\bar{r}_t^*$) is the short term US real interest rates.

CHAPTER **4**

UNCOVERING THE HIT-LIST FOR SMALL INFLATION TARGETERS: A BAYESIAN STRUCTURAL ANALYSIS

Abstract*

We estimate underlying structural macroeconomic policy objectives of three of the earliest explicit inflation targeters within the context of a small open economy DSGE model. We assume central banks set policy optimally, such that we can reverse engineer policy objectives from observed time series data. Joint tests of the posterior distributions of these policy preference parameters suggest that the central banks are very similar in their overall objective. None of the central banks show a concern for stabilizing the real exchange rate. All three central banks share a concern for minimizing the volatility in the change in the nominal interest rate. We also show that the resulting optimal policy rule responds to exchange rate movements, even in the case where the central banks do not explicitly care about exchange rate stabilization. This result is also corroborated by results from an alternative simple-rule characterization and estimation of central bank behavior. These last two findings point to the pitfalls of making inferences from the level of ad-hoc simple rules about what central banks may care about.

4.1 Introduction

IN THE RECENTLY popular class of dynamic stochastic general equilibrium (DSGE) models, private economic agents such as consumers and firms are often modeled as optimizing decision makers. However, central bank behavior is typically described by a reduced-form monetary policy rule rather than a set of deeper monetary policy objectives often

*Chapter (4) is a summary of joint work with Timothy Kam (ANU) and Kirdan Lees (RBNZ) published in the *Journal of Money, Credit and Banking*, volume 41, issue 4, p583-618.

institutionally defined. Empirical estimates obtained from reduced-form monetary policy rules are functions of both the underlying structure of the economy and policy objectives. Characterizing policy from the level of policy objectives allows one to distinguish changes in the policy rule that results from changes to structural parameters in the economy, from, changes in policy objectives.

Modeling the deeper central bank objectives enables us to empirically infer the importance a central bank places on particular institutionally-defined monetary policy objectives such as inflation stabilization and output stabilization. In this paper, we apply this simple idea to a new empirical problem for small open economies. We treat the central bank as an optimizing agent, thus placing the central bank on the same footing as the other optimizing agents in the model economy. We identify the macroeconomic objectives of three of the earliest explicit small-open-economy inflation targeters - Australia, Canada and New Zealand, over the period 1990Q1 - 2005Q3. We estimate the same DSGE model for each country and reverse engineer stabilization objectives that are conditioned on the structure of each economy.

4.1.1 Contributions

A considerable number of studies utilize loss function parameters for optimal monetary policy experiments (e.g. Rudebusch and Svensson, 1999; Levin and Williams, 2003; Del Negro and Schorfheide, 2005). However, Dennis (2006) argues that typical loss function parameterizations may be inconsistent with the data. In particular, these yield aggressive policy rules that are inconsistent with the observed interest rate smoothing behavior documented in the literature (see Lowe and Ellis, 1997).

This paper contributes to this debate by explicitly identifying the loss function parameters for three microfounded small open economies conditioned on historical data. In particular, we ask the following questions: (i) whether our sample central banks explicitly care about stabilizing the real exchange rate; and, (ii) whether their policy preferences are similar overall. In doing so, our approach yields a deeper insight into institutionally defined policy *preferences*. This is in contrast to empirical analyses (e.g. Lubik and Schorfheide, 2007) that inquire into the *behavioral* responses of central banks. We also provide a link between our empirical analysis of uncovering what central bank *preferences* are and the resulting implication for policy *behavior*. We argue and show that it is straightforward to derive the mapping from preferences to equilibrium behavior (i.e. reduced-form policy rules) for the central banks, but the converse is not the case, if we begin the analysis from an ad-hoc *behavioral rule.*

The results from our analysis will help inform monetary policy experiments seeking optimal policy rules for open economy inflation targeters. Estimates of macroeconomic policy objectives can potentially enhance both the transparency and accountability of the practical implementation of monetary policy. Most inflation targeting central banks describe themselves as "flexible" in their approach to inflation targeting, implying central banks objectives embody factors beyond simply inflation. However, while central banks are often explicit about the macroeconomic variables they are concerned with, the trade-offs across these macroeconomic objectives are never elucidated. We believe transparency is enhanced by providing explicit statements of how alternative stabilization objectives are weighted (see Svensson, 2000) and our analysis provides such statements.

Finally, historical estimates of stabilization objectives (conditioned on an explicit structural and microfounded model) provide a framework for central bank boards or government agencies tasked with assessing central bank performance. For example, clause 4(b) of New Zealand's 2008 Policy Targets Agreement (PTA) – the agreement between the Governor of the Reserve Bank of New Zealand and the Minster of Finance – states that: "In pursuing its price stability objective, the Bank shall seek to avoid unnecessary instability in output, interest rates and the exchange rate". Simply observing the unconditional volatilities of the goal variables in the PTA cannot provide an examination of monetary policy, since these volatilities are also affected by non-policy structural features of the economy.

Another contribution from our exercise is to provide alternative full-information Bayesian estimates on a popular class of open economy New-Keynesian model parameters under the assumption of optimal monetary policy. Our Bayesian posterior estimates may be used for comparison with existing estimation strategies that are conditional on simple policy rules, or simply for users who wish to calibrate their models for policy simulations.

4.1.2 Main findings

We find that none of the central banks show a concern for stabilizing the real exchange rate. However, all three central banks share a concern for minimizing the volatility in the change in the nominal interest rate. According to our analysis, the Reserve Bank of Australia places the most weight on minimizing the deviation of output from trend. In contrast to existing applications of Bayesian econometrics to the evaluation of DSGE models, we also compare the posterior distributions of the central banks' preference parameters. Tests of the posterior distributions of these policy preference parameters suggest that the central banks have very similar preferences.

We also show that the resulting optimal policy rule still responds to exchange rate movements, even in the case where the central banks do not explicitly care about exchange rate stabilization. We also estimate a class of simple rules, as in Lubik and Schorfheide (2007), as an alternative representative of central bank behavior, and this exercise also corroborates the exchange rate response result in the optimal policy. The former optimal rules may be comparable to the simple rules estimates. The latter, as we show, may be misleading when used in empirical exercises to infer what central banks really care about.

4.1.3 Related literature

Several authors report empirical estimates of the objectives of the US Federal Reserve system. Salemi (1995) provides the earliest estimates based on a VAR model. In contrast to the mandate of the Federal Reserve, Favero and Rovelli (2003), Castelnuovo and Surico (2004) and Dennis (2006) find either small or insignificant weights on output stabilization over the Volcker-Greenspan period. In addition, Ozlale (2005) and Dennis (2006) find a significant weight on interest rate smoothing in the context of aggregate empirical models without explicit optimising firms and households. Furthermore Cecchetti et al. (2001) presents cross country estimates from a non-structural model that has little dynamic structure. Nimark (2006) provides estimates of macroeconomic objectives for both the Reserve Bank of Australia (RBA) and the Federal Reserve that suggest the RBA puts more weight on output stabilization and interest smoothing than the US Federal Reserve. However, Nimark's paper uses a closed economy model that is silent on any preference for mitigating exchange rate volatility. Given Australia's degree of openness and the focus of this paper, an open economy model appears necessary to approximate the constraint the RBA faces in implementing monetary policy.

In contrast to Nimark (2006), we estimate central bank preferences for Australia, Canada and New Zealand, within an open economy DSGE model. Furthermore, the DSGE model provides an incomplete exchange rate pass-through channel in import prices such that deviations from the law of one price (or alternatively real exchange rate deviations) matter for the economies. Such a model provides a rationale for incorporating central bank preferences over exchange rate movements, as indicated in practice by New Zealand's PTA for example.

Our DSGE model extends Monacelli (2005) by introducing endogenous persistence on both the aggregate demand and supply sides of the model and has similarities with Justiniano and Preston (2009). This feature is crucial for bringing the model closer to the data, as shown in Fukac and Pagan (2008). Thus, for example, a simpler purely forward-looking model used in Lubik and Schorfheide (2007) may be misspecified.

We use Bayesian methods to estimate the model and apply an identical prior to each of the countries in our sample. We make inferences regarding central bank preferences using Bayesian posterior distributions on the model parameters. Our Bayesian methodology closely follows related papers in the literature (see Smets and Wouters, 2003 and Rabanal and Rubio-Ramírez, 2005 for example). Although we focus on policy objectives, the estimates from our DSGE model should also help inform a growing empirical open economy literature (see e.g. Justiniano and Preston, 2009; Lubik and Schorfheide, 2005, 2007).

The paper is organized as follows. Section (4.2) sets out the model. Section (4.3) outlines the empirical methodology and describes the data we use. Sections (4.4) and (4.5) contain our main results. We make concluding comments in section (4.6) .

4.2 The model

4.2.1 The average household

The stylized economy is similar to the open economy model in Monacelli (2005) and Justiniano and Preston (2009). The economy has identical households with a total population of measure 1. We assume the functional form for period utility:

$$U(C_t, H_t, N_t) = \frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}, \tag{4.1}$$

where C_t is an index of consumption goods, $H_t = hC_{t-1}$ is an external habit stock, with $h \in (0,1)$ capturing the degree of habit persistence and N_t is labour hours.

Define the prices for each differentiated home and foreign good of type $i \in [0,1]$ and $j \in [0,1]$, respectively, as $P_{H,t}(i)$ and $P_{F,t}(j)$. Let B_t be an Arrow security that pays out contingent on the state of the world and $W_t N_t$ be the total wage income. The stochastic discount factor is $\mathbb{E}_t Q_{t,t+1}$ such that it will be inversely related to the gross return on a nominal riskless one-period bond, $\mathbb{E}_t Q_{t,t+1} = R_t^{-1}$.

The price-taking average household solves a Bellman equation problem:

$$V(B_t, H_t) = \max_{C_t, N_t} U(C_t, H_t, N_t) + \beta \mathbb{E}_t \{V(B_{t+1}, H_{t+1})\}; \qquad \beta \in (0,1) \tag{4.2}$$

subject to the sequence of budget constraints

$$B_t \geq \int_0^1 \int_0^1 [P_{H,t}(i) C_{H,t}(i) + P_{F,t}(j) C_{F,t}(j)] \, di dj + \mathbb{E}_t Q_{t,t+1} B_{t+1} - W_t N_t. \tag{4.3}$$

with B_0 given.

The consumption index C_t is linked to a continuum of domestic, $C_{H,t}(i)$, and foreign goods, $C_{F,t}(j)$, which exist on the interval of $[0,1]$ where:

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta-1}{\eta}}, \tag{4.4}$$

and

$$C_{H,t} = \left[\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}}, \qquad C_{F,t} = \left[\int_0^1 C_{F,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{4.5}$$

The elasticity of substitution between home and foreign goods is given by $\eta > 0$ and the elasticity of substitution between goods within each goods category (home and foreign) is $\varepsilon > 0$. Optimal allocation of the household expenditure across each good type gives rise to the demand functions:

$$C_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} C_{H,t}, \qquad C_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\varepsilon} C_{F,t} \tag{4.6}$$

for all $i, j \in [0,1]$, where the aggregate price levels are defined as

$$P_{H,t} = \left(\int_0^1 P_{H,t}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}, \qquad P_{F,t} = \left(\int_0^1 P_{F,t}(j)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}, \tag{4.7}$$

and optimal consumption demand of home and foreign goods can be derived, respectively, as

$$C_{H,t} = (1-\alpha) \left(\frac{P_{H,t}}{P_t} \right)^{-\eta} C_t, \qquad C_{F,t} = \alpha \left(\frac{P_{F,t}}{P_t} \right)^{-\eta} C_t.$$

Substitution of these demand functions into (4.4) yields the consumer price index as

$$P_t = \left[(1-\alpha) P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{4.8}$$

The intratemporal condition relating labour supply (the marginal rate of substitution between consumption and leisure) to the real wage (the marginal product of labour) must also be satisfied:

$$(C_t - H_t)^{\sigma} N_t^{\varphi} = \frac{W_t}{P_t} \tag{4.9}$$

Finally, intertemporal optimality for the household decision problem must satisfy

$$\beta \left(\frac{C_{t+1} - H_{t+1}}{C_t - H_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+1}}\right) \mu_t(h^{t+1}|h^t) = Q_{t,t+1}. \tag{4.10}$$

for all dates and state $t \in \mathbb{N}$, and $\mu_t(h^{t+1}|h^t)$ denotes the probability measure on the continuation history (or state, in the Markovian case), conditional on the realized history. Taking conditional expectations yields the familiar stochastic Euler equation

$$\beta R_t \mathbb{E}_t \left\{ \left(\frac{C_{t+1} - H_{t+1}}{C_t - H_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+1}}\right) \right\} = 1.$$

4.2.2 International risk sharing and relative prices

The rest of the world, denoted by variables and parameters with an asterisk, solves a similar problem to the small open economy. Specifically, the rest of the world is the limiting case of a closed economy, where $\alpha^* \to 1$. First-order conditions for optimal labour supply and consumption, analogues of (4.9) and (4.10), also hold for the rest of the world. Given identical global preferences and complete international markets, we obtain perfect risk sharing,

$$\beta \left(\frac{C_{t+1} - H_{t+1}}{C_t - H_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+1}}\right) = Q_{t,t+1} = \beta \left(\frac{C_{t+1}^* - H_{t+1}^*}{C_t^* - H_t^*}\right)^{-\sigma} \left(\frac{P_t^*}{P_{t+1}^*}\right) \left(\frac{\tilde{e}_t}{\tilde{e}_{t+1}}\right) \tag{4.11}$$

for all dates and states, where $\tilde{e}_t$ is the nominal exchange rate. We also define conventionally the real exchange rate as

$$\mathcal{Q}_t = \tilde{e}_t P_t^* / P_t. \tag{4.12}$$

Assuming ex ante identical countries, and no preference shocks to the rest of the world, this implies that

$$C_t - hC_{t-1} = \vartheta^* \left(C_t^* - hC_{t-1}^* \right) Q_t^{\frac{1}{\sigma}}. \tag{4.13}$$

where $\vartheta^* = 1$ imposes ex ante symmetry of countries and zero net foreign asset holdings.

Let $c_t := \ln(C_t/C_{ss}), y_t^* := \ln(Y_t^*/Y_{ss}^*) = \ln(C_t^*/C_{ss}^*)$, and $q_t := \ln(Q_t/Q_{ss}^*)$, denote the percentage deviation of home consumption, foreign output and real exchange rate from their respective steady states, where X_{ss} is the deterministic steady state value of a variable X_t. Then, a log-linear approximation of (4.13) is

$$c_t - hc_{t-1} = y_t^* - hy_{t-1}^* + \frac{1-h}{\sigma} q_t. \tag{4.14}$$

Complete markets thus imply that global consumption will be perfectly correlated in the absence of deviations in the real exchange rate.

From (4.11) we can also derive the no-arbitrage condition for exchange rates, or the uncovered interest parity condition

$$R_t - R_t^* \frac{\widetilde{e}_t}{\widetilde{e}_{t+1}} = 0, \tag{4.15}$$

which must hold for all states and dates in a globally complete markets setting. A log-linear approximation of this, and taking expectations with respect to the time-t sigma algebra, yields the familiar nominal interest parity condition:

$$\mathbb{E}_t e_{t+1} - e_t = r_t - r_t^* \tag{4.16}$$

where $e_t := \ln(\widetilde{e}_t/e_{ss})$, and the domestic and foreign rates of return are, $r_t = R_t - 1$ and $r_t^* = R_t^* - 1$, respectively.

We can define the terms of trade as the ratio of the foreign goods price index to the home goods price index. In log-linear terms this is

$$s_t = p_{F,t} - p_{H,t}. \tag{4.17}$$

4.2.3 Production and optimal pricing

There is a continuum of monopolistically competitive domestic producers $i \in [0,1]$ that produce differentiated goods and import retailers $j \in [0,1]$ that add markups to goods imported at world prices. We employ similar pricing assumptions as in Justiniano and Preston (2009) and Smets and Wouters (2003). In particular, the conventional Calvo-style optimal pricing models and partial inflation indexation for non-optimizing price setters. This allows inflation to be partly a jump variable and also partially backward-looking.

4.2.3.1 Domestic goods firms

Domestic goods firms operate a linear production technology, $Y_{H,t}(i) = \epsilon_{a,t} N_t(i)$ where $\epsilon_{a,t}$ is an exogenous domestic technology shock. Domestic firms face an independent signal that allows them to set prices optimally each period with probability $1 - \theta_H$. In each period t, the remaining fraction $\theta_H \in (0,1)$ of firms partially index their price to take into account of aggregate domestic inflation according to the simple rule

$$P_{H,t}(i) = P_{H,t-1}(i) \left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta_H} \tag{4.18}$$

where $\delta_H \in [0,1]$ measures the degree of inflation indexation. Since all firms either receive the same signal to reset prices or do not receive any signal, they will choose the same pricing strategies. Given Calvo price setting, it is straightforward to define the dynamics of the aggregate price level of the domestic goods. In particular, define the evolution of the aggregate home goods price index as

$$P_{H,t} = \left\{ (1-\theta_H)\left(P_{H,t}^{new}\right)^{1-\varepsilon} + \theta_H \left[P_{H,t-1} \left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta_H} \right]^{1-\varepsilon} \right\}^{\frac{1}{1-\varepsilon}}, \tag{4.19}$$

Consider a candidate firm i that had set its price optimally in time t as $P_{H,t}(i)$. Suppose at some time $t+s$, $s \geq 0$, the price $P_{H,t}(i)$ still prevails. Then the firm will have to face the demand for its product given by the demand constraint

$$Y_{H,t+s}(i) = \left[\frac{P_{H,t}(i)}{P_{H,t+s}} \left(\frac{P_{H,t+s-1}}{P_{H,t-1}}\right)^{\delta_H} \right]^{-\varepsilon} \left(C_{H,t+s} + C_{H,t+s}^{*}\right). \tag{4.20}$$

Note that market demand at time $t+s$ will take into account the inflation indexation between t and $t+s$.

Firms that set optimal prices do so to maximize their present value of the stochastic stream of profits. A candidate firm i solves

$$\max_{P_{H,t}(i)} \mathbb{E}_t \sum_{s=0}^{\infty} Q_{t,t+s}\theta_H^s Y_{H,t+s}(i) \left[P_{H,t}(i) \left(\frac{P_{H,t+s-1}}{P_{H,t-1}} \right)^{\delta_H} - P_{H,t+s} MC_{H,t+s} \exp(\epsilon_{H,t+s}) \right] \tag{4.21}$$

subject to (4.20) for $t, s \in \mathbb{N}$ and the technological constraint given by real marginal cost,

$$MC_{H,t+s} = \frac{W_{t+s}}{\epsilon_{a,t+s} P_{H,t+s}} \tag{4.22}$$

Note that we also allow for a structural shock to real marginal cost given by $\epsilon_{H,t} \sim i.i.d.(0, \sigma_H)$. This has the interpretation of an independent cost-push shock to domestic goods producers.

The first order necessary condition characterizing domestic firms' optimal pricing function in a symmetric equilibrium is

$$\mathbb{E}_t \sum_{s=0}^{\infty} \theta_H^s Q_{t,t+s} Y_{H,t+s}(i) \left[\widetilde{P}_{H,t} \left(\frac{P_{H,t+s-1}}{P_{H,t-1}} \right)^{\delta_H} - \left(\frac{\varepsilon}{\varepsilon - 1} \right) P_{H,t+s}(i) MC_{H,t+s} \exp(\epsilon_{H,t+s}) \right] = 0 \tag{4.23}$$

Let the home goods inflation rate be $\pi_{H,t} := \ln(P_{H,t}/P_{H,t-1})$ and $y_t := \ln(Y_t/Y_{ss})$ be the percentage deviation of home output from steady state. Denote the real marginal cost in percentage deviation terms from its deterministic steady-state $mc_{H,ss} = [\epsilon/(\epsilon-1)]^{-1}$ as $mc_{H,t}$. In appendix (4.A.1) we derive the log-linear approximation of the optimal pricing decision rule, which can easily be expressed as the following Phillips curve for domestic goods inflation:

$$\pi_{H,t} - \delta_H \pi_{H,t-1} = \beta (\mathbb{E}_t \pi_{H,t+1} - \delta_H \pi_{H,t}) + \lambda_H (mc_{H,t} + \epsilon_{H,t}) \tag{4.24}$$

where $\lambda_H = (1 - \beta\theta_H)(1 - \theta_H)\theta_H^{-1}$ and

$$mc_{H,t} = \varphi y_t - (1 + \varphi)\epsilon_{a,t} + \alpha s_t + \frac{\sigma}{1-h}(y_t^* - h y_{t-1}^*) + q_t + \epsilon_{c,t}. \tag{4.25}$$

4.2.3.2 Import retail firms

Import retailers are assumed to purchase imported goods at competitive world prices. However, these firms act as monopolistically competitively re-distributors of these goods. This creates a gap between the price of imported goods in domestic currency terms and the domestic retail price of imported goods. Define this law of one price (LOP) gap in log-linear terms as:

$$\psi_{F,t} = e_t + p_t^* - p_{F,t}. \tag{4.26}$$

The pricing behavior for imports retailers is similar to that of domestic goods producers. In short, the evolution of the imports price index is given by

$$P_{F,t} = \left\{ (1-\theta_F) \left(P_{F,t}^{new}\right)^{1-\varepsilon} + \theta_F \left[P_{F,t-1} \left(\frac{P_{F,t-1}}{P_{F,t-2}} \right)^{\delta_F} \right]^{1-\varepsilon} \right\}^{\frac{1}{1-\varepsilon}} \tag{4.27}$$

An importing firm j at some time $t+s$, $s \geq 0$, faces the demand for its product given by the demand constraint

$$Y_{F,t+s}(j) = \left[\frac{P_{F,t}(j)}{P_{F,t+s}} \left(\frac{P_{F,t+s-1}}{P_{F,t-1}} \right)^{\delta_F} \right]^{-\varepsilon} C_{F,t+s}. \tag{4.28}$$

Note that market demand at time $t+s$ will take into account the inflation indexation between t and $t+s$. A candidate firm j solves

$$\max_{P_{F,t}(j)} \mathbb{E}_t \sum_{s=0}^{\infty} Q_{t,t+s} \theta_F^s Y_{F,t+s}(j) \left[P_{F,t}(j) \left(\frac{P_{F,t+s-1}}{P_{F,t-1}} \right)^{\delta_F} - \tilde{e}_{t+s} P_{F,t+s}^*(j) \exp\left(\epsilon_{F,t+s}\right) \right] \tag{4.29}$$

subject to (4.28) for $t, s = 0, 1, \ldots$. Here we also allow for a structural shock to marginal cost (world price of good j) given by $\epsilon_{F,t} \sim i.i.d.(0, \sigma_F)$. This has the interpretation of an independent cost-push shock to imports retailers.

The first order necessary condition characterizing the import retailers' optimal pricing function in the symmetric equilibrium is

$$\mathbb{E}_t \sum_{s=0}^{\infty} \theta_F^s Q_{t,t+s} Y_{F,t+s}(j) \left[\widetilde{P}_{F,t} \left(\frac{P_{F,t+s-1}}{P_{F,t-1}} \right)^{\delta_F} - \left(\frac{\varepsilon}{\varepsilon - 1} \right) \tilde{e}_{t+s} P_{F,t+s}(j) \exp\left(\epsilon_{F,t+s}\right) \right] = 0 \tag{4.30}$$

Let $\pi_{F,t} := \ln(P_{F,t}/P_{F,t-1})$. Log-linearizing this around the non-stochastic steady state yields

$$\pi_{F,t} = \beta \mathbb{E}_t \left(\pi_{F,t+1} - \delta_F \pi_{F,t} \right) + \delta_F \pi_{F,t-1} + \lambda_F \left(\psi_{F,t} + \epsilon_{F,t} \right), \tag{4.31}$$

where $\lambda_F = (1 - \beta\theta_F)(1 - \theta_F)\theta_F^{-1}$.

4.2.4 Terms of trade, real exchange rate and market clearing

We can derive a relationship between the terms of trade, the real exchange rate and the LOP gap. Specifically, log-linearizing the real exchange rate definition (4.12) around the deterministic steady state we have

$$q_t = e_t + p_t^* - p_t. \tag{4.32}$$

From (4.26) we can re-write this as

$$q_t = \psi_{F,t} + p_{F,t} - p_t \approx \psi_{F,t} - (1-\alpha)(p_{F,t} - p_{H,t}) = \psi_{F,t} - (1-\alpha)s_t. \tag{4.33}$$

where the last term is obtained by log-linearizing the CPI definition and then using (4.17).

The remaining market-clearing condition to consider is in the product markets. In the rest of the world we have the limit of a closed economy so that $y_t^* = c_t^*$ for all t. In the small open economy, this requires that domestic output equals total domestic and foreign demand for home produced goods. In log-linear terms this is

$$y_t = c_{H,t} + c_{H,t}^*.$$

Since the demand for home and foreign consumption goods can be written in log-linear form as $c_{H,t} = (1-\alpha)[\alpha\eta s_t + c_t]$ and $c_{H,t}^* = \alpha[\eta(s_t + \psi_{F,t}) + y_t^*]$, respectively, we can write

$$y_t = (2-\alpha)\alpha\eta s_t + (1-\alpha)c_t + \alpha\eta\psi_{F,t} + \alpha y_t^*. \tag{4.34}$$

4.2.5 Log-linear approximation of the model

In this section we summarize the log-linearized equilibrium conditions. The consumption Euler equation is obtained by log-linearizing (4.10) and taking expectations conditional on the time-t sigma algebra:

$$c_t - hc_{t-1} = \mathbb{E}_t(c_{t+1} - hc_t) - \frac{1-h}{\sigma}(r_t - \mathbb{E}_t\pi_{t+1}). \tag{4.35}$$

Domestic goods inflation is given by (4.24) and substituting out the term $mc_{H,t}$:

$$\pi_{H,t} = \beta \mathbb{E}_t \left(\pi_{H,t+1} - \delta_H \pi_{H,t}\right) + \delta_H \pi_{H,t-1} \\ + \lambda_H \left[\varphi y_t - (1+\varphi)\,\epsilon_{a,t} + \alpha s_t + \frac{\sigma}{1-h}\left(c_t - hc_{t-1}\right)\right] + \lambda_H \epsilon_{H,t} \quad (4.36)$$

Imports inflation is given by (4.31) and substituting out the term $\psi_{F,t}$ with (4.33):

$$\pi_{F,t} = \beta \mathbb{E}_t \left(\pi_{F,t+1} - \delta_F \pi_{F,t}\right) + \delta_F \pi_{F,t-1} + \lambda_F \left[q_t - (1-\alpha)\, s_t\right] + \lambda_F \epsilon_{F,t} \quad (4.37)$$

Leading (4.32) one period, first-differencing, taking the time-t conditional expectations operator, and then combining with (4.16) yields the real interest parity condition,

$$\mathbb{E}_t \left(q_{t+1} - q_t\right) = \left(r_t - \mathbb{E}_t \pi_{t+1}\right) - \left(r_t^* - \mathbb{E}_t \pi_{t+1}^*\right) + \epsilon_{q,t}. \quad (4.38)$$

First differencing the terms of trade equation (4.17) we have

$$s_t - s_{t-1} = \pi_{F,t} - \pi_{H,t} + \epsilon_{s,t}. \quad (4.39)$$

Goods market clearing (4.34) in combination with (4.26) yields

$$y_t = (1-\alpha)\, c_t + \alpha\eta q_t + \alpha\eta s_t + \alpha y_t^* \quad (4.40)$$

First-differencing the CPI definition yields CPI inflation,

$$\pi_t = (1-\alpha)\, \pi_{H,t} + \alpha \pi_{F,t} \quad (4.41)$$

Exogenous stochastic processes for terms-of-trade, technology and real-interest-parity shocks:

$$\epsilon_{j,t} = \rho_j \epsilon_{j,t-1} + \nu_{j,t}; \quad \rho_j \in (0,1)\,, \nu_j \sim i.i.d.\left(0, \sigma_j^2\right) \quad (4.42)$$

for $j = s, a, q$. Recall the marginal cost shocks in the home goods and import retailers profit functions are $\epsilon_H \sim i.i.d.(0, \sigma_H)$ and $\epsilon_F \sim i.i.d.(0, \sigma_F)$, respectively.

Finally, for simplicity we assume that the foreign processes $\{\pi^*, y^*, r^*\}$ are given by uncorrelated AR(1) processes:[1]

$$\begin{pmatrix} \pi_t^* \\ y_t^* \\ r_t^* \end{pmatrix} = \begin{pmatrix} a_1 & 0 & 0 \\ 0 & b_2 & 0 \\ 0 & 0 & c_3 \end{pmatrix} \begin{pmatrix} \pi_{t-1}^* \\ y_{t-1}^* \\ r_{t-1}^* \end{pmatrix} + \begin{pmatrix} \sigma_{\pi^*} & 0 & 0 \\ 0 & \sigma_{y^*} & 0 \\ 0 & 0 & \sigma_{r^*} \end{pmatrix} \begin{pmatrix} \nu_{\pi^*,t} \\ \nu_{y^*,t} \\ \nu_{r^*,t} \end{pmatrix}, \tag{4.43}$$

where $(\nu_{\pi^*,t}, \nu_{y^*,t}, \nu_{r^*,t}) \sim N(0, I_3)$.

4.2.6 Central bank preferences

Since the model possesses incomplete exchange rate pass through in the short run (which gives rise to persistent gaps in the law of one price for imported goods) there is a potential role for the central bank to minimize these gaps. Alternatively, given the terms of trade s_t from equation (4.33), the central bank can target the real exchange rate q_t to stabilize these law of one price gaps, $\psi_{F,t}$.

Let $\widetilde{\pi}_t := \sum_{i=0}^{3} \pi_{t-i}/4$ denote the annual inflation rate in the quarterly model. For computational and estimation purposes, we suppose the one-period general loss function for the central bank is quadratic:[2]

$$L\left(\widetilde{\pi}_t, y_t, q_t, r_t - r_{t-1}\right) = \frac{1}{2}\left[\widetilde{\pi}_t^2 + \mu_y y_t^2 + \mu_q q_t^2 + \mu_r \left(r_t - r_{t-1}\right)^2\right] \tag{4.44}$$

The parameters $\mu_y, \mu_q, \mu_r \in [0, +\infty)$ express the concern with output stabilization, real exchange rate stabilization and targeted interest rate smoothing respectively. These objectives are expressed relative to a concern for annual inflation, $\widetilde{\pi}_t$, that is normalized to one. This specification of macroeconomic objectives encompasses the expressed goals of so-called "flexible" inflation targeting central banks by allowing for positive weights to the arguments other than inflation in the loss function.

In addition to the output argument, our loss function specification includes a weight on the change in the interest rate. Central banks typically change policy in successive incremental changes in the policy rate in the same direction and many papers included the

[1]Our earlier estimates have also utilized assumptions on $\{\pi^*, y^*, r^*\}$ as being generated by a VAR(1) process and also a limiting closed-economy New-Keynesian model under a first best fiscal-monetary policy arrangement. The former is statistically more flexible than our current assumption, and the latter is a stricter theoretical restriction on the data. We found that these assumptions do not matter very much. Thus, a reasonable middle ground for statistical flexibility and parsimony in our model parameterization would be to use our current assumption.

[2]Our aim is recover the macroeconomic objectives of open economy central banks. We take no stance on normative design aspects of what these objectives should be. Rather, we simply seek what our three open economy inflation targeters have tried to achieve over the sample period.

change in the interest rate in the loss function (see Svensson (2000), for example). Empirically the change in the interest rate term matters. Dennis (2006) shows that a high weight should be attached to the change in interest rates to capture the dynamics on interest rates in the US data. Furthermore, we allow for the possibility that our open economy central banks may be concerned with stabilising the real exchange rate. Obstfeld and Rogoff (1998) suggest there are costs to exchange rate volatility that generates consumption volatility and costly hedging activities on the part of firms, although Bergin et al. (2007) demonstrate that the costs of exchange rate volatility may be small.

From a public finance perspective, such assignments of policy objective functions are clearly ad hoc. For example, the literature following the method of deriving an approximate private-welfare-based loss function in Woodford (2003) would argue that the loss function parameters are not "free" but must be constrained by the preferences of the representative household. However, in defence of our approach we make three arguments.

First, mapping a second-order approximation of the welfare maximizing central-bank loss function from household preferences in closed form (see e.g. Benigno and Woodford, 2008) generally imposes highly nonlinear structural restrictions on the loss function parameters. Since these restrictions on the approximate loss function are likely to be misspecified with respect to, or too demanding on, the empirical data generating process, we have chosen to treat the loss function parameters as free. Second, from an empirical perspective our loss function captures the goal variables Australia, Canada and New Zealand have institutionally defined as monetary policy objectives. In the case of New Zealand, there is a legislated set of policy objectives: price stability, output, interest rates and the exchange rate. Finally, our formulation of objectives is consistent with the monetary policy literature that seeks to evaluate the efficacy of alternative monetary policy rules using quadratic loss functions (see e.g. Rudebusch and Svensson, 1999; Levin and Williams, 2003).

4.2.6.1 Optimal time-consistent monetary policy

To keep the empirical structure arising from optimal policy manageable, we assume that the central bank must implement optimal policy which is time consistent. In particular, we restrict our notion of time-consistency to a class of dynamic games characterized by Markov-perfect equilibrium payoffs and strategies.[3]

[3] Our methodology also encodes the option for solving and estimating the model under the assumption that central banks commit to an ex-ante optimal monetary policy plan. However, this alternative assumption would be beyond the scope of this paper.

Define $W(\epsilon_t, z_{t-1})$ as the value function of the central bank's optimal action at time t given state $z_{t-1} := \{c_{t-1}, y^*_{t-1}, \pi_{H,t-1}, \pi_{F,t-1}\}$ and $\epsilon_t := (\pi^*_t, y^*_t, r^*_t, \{\epsilon_{j,t}\})$, for $j = s, a, H, F, q$. A strategy of the central bank is a sequence of policy functions $\{r_t(\epsilon_t, z_{t-1})\}_{t=0}^{\infty}$ and the private sector's collective strategy would be the sequence of allocation and pricing functions $\{c_t, \pi_{H,t}, \pi_{F,t}, q_t, s_t, y_t\}_{t=0}^{\infty}$. In principle, we can and we do, characterize our Markov-perfect equilibrium as if it were supported by central bank strategies that involve picking a sequence of all pricing and allocation functions, and private sector strategies then would be to pick expectations of such future outcomes under the central bank strategy which are consistent with the equilibrium definition. More precisely, we define an equilibrium under time-consistent optimal monetary policy as follows.

Definition 1 (Linear-quadratic Markov-perfect equilibrium (LQ-MPE)) *A LQ-MPE in this economy is a sequence of allocation and pricing functions,*

$$\{u_t(\epsilon_t, z_{t-1})\}_{t=0}^{\infty} := \{c_t, \pi_{H,t}, \pi_{F,t}, q_t, r_t, s_t, y_t\}_{t=0}^{\infty},$$

that satisfies:

(i) The central bank's Bellman equation,

$$W(\epsilon_t, z_{t-1}) = \min_{u_t} L(\widetilde{\pi}_t, y_t, q_t, r_t - r_{t-1},) + \beta \mathbb{E}_t W(\epsilon_{t+1}, z_t) \tag{4.45}$$

subject to (4.35)-(4.41),

(ii) Private sector competitive equilibrium conditions (4.35)-(4.41) with conditional expectations consistent with the solution to the problem (4.45), and

(iii) Given the exogenous stochastic processes (4.42)-(4.43).

Notice that the central bank takes private expectations as given when it sequentially optimizes. We compute solutions to the familiar LQ-MPE problem using the algorithm of Dennis (2004a). In the existing Bayesian literature on such models, one often estimates a reduced form Taylor type rule. However, when the central bank optimizes under discretion, it can be shown, as in Dennis (2004a), that policy preference parameters and deep parameters place non-linear constraints on a reduced-form policy feedback rule. To make the model stochastically richer, we will linearly append a noise term to the resulting optimal interest rate rule, $r_t(\epsilon_t, z_{t-1})$, denoted as $\epsilon_{r,t} \sim i.i.d.(0, \sigma_r^2)$, which has the usual interpretation of an exogenous monetary policy shock.

4.3 Empirical investigation

The first question we would like to ask is the following: Do these flexible inflation-targeting central banks place much weight on exchange rate deviations? Existing papers have focused on whether and how much central banks *respond* to exchange rates at the behavioral level of reduced form interest-rate rules (see Lubik and Schorfheide, 2007 and Justiniano and Preston, 2009). The second question is whether the preferences of the central banks are "different" or "similar". We address these empirical questions using Bayesian empirical methods on the model structure we have.

4.3.1 Estimation strategy

We are interested in estimating the structural or deep parameters of our model and variations of it. We classify a candidate model M by its list of parameters, Θ. We proceed by estimating two versions of the model for each country. The first version utilizes the general one-period loss specification in (4.44). We will call this larger model M_1 in subsequent discussions.

The set of parameters to be estimated are the following central back preference parameters, $\{\mu_y, \mu_r, \mu_q\}$, the private sector deep parameters, $\{h, \sigma, \phi, \eta, \delta_H, \delta_F, \theta_H, \theta_F\}$ and the parameters for exogenous processes $\{a_1, b_2, c_3, \rho_a, \rho_q, \rho_s, \sigma_H, \sigma_F, \sigma_a, \sigma_q, \sigma_s, \sigma_{\pi^*}, \sigma_{y^*}, \sigma_{r^*}, \sigma_r\}$.[4]

The second version, which we shall denote as model M_2, uses (4.44) but restricting $\mu_q = 0$. We can then address the first question by using Bayesian posterior odds comparisons to see if a model with or without $\mu_q = 0$ is more probable, all other things equal.

Our estimation procedure uses the random-walk-Metropolis Markov chain Monte Carlo (MCMC) method. We outline this popular algorithm in Appendix (4.A.2) . Table (4.1) summarizes the prior marginal density functions we use on each estimated parameter in the models. We use fairly agnostic or dispersed prior densities as evident in the wide 95% confidence intervals around the prior means.[5] To ensure that theoretical restrictions on the

[4]There is very little information in the data to help us pin down the discount factor β and imports share in domestic consumption, α, so we set these as 0.99 and 0.45, respectively.

[5]We have also conducted alternative MCMC simulations based on competing prior density specifications. Our reported results are generally robust to these prior specifications. These less interesting results are not reported in the paper.

parameter space are satisfied, we draw from prior densities that are restricted to the appropriate supports. For example, we define a prior density for the Calvo parameter θ_H to have the domain $(0, 1)$.

For each candidate Θ, the linear rational expectations (RE) system including the optimal monetary policy problem is solved to obtain an affine solution, $\{\mathbf{A}(\Theta), \mathbf{C}(\Theta)\}$, in terms of the endogenous state variables y_t and the central-bank policy decision variables, x_t (which is just the scalar r_t in our case):

$$\xi_{t+1} = \mathbf{A}(\Theta)\,\xi_t + \mathbf{C}(\Theta)\,\varepsilon_{t+1} \tag{4.46}$$

where $\xi_t := (y_t, x_t)$. We can map some of the variables in ξ_t to a vector of observable variables, y_t^o using an observation equation:

$$y_t^o = \mathbf{G}\xi_t. \tag{4.47}$$

We set the length of the parameters' Markov chain to be $N = 2 \times 10^6$ draws and remove the first half of the sample (the "burn-in" period) to remove any effect of the initial condition of the Markov chain $\{\Theta_n\}_{n \in \mathbb{N}}$ and also perform some diagnostic tests to check that our MCMC procedure has converged to its stable, invariant distribution.

4.3.2 Data

Each model we consider has nine structural shocks. To avoid stochastic singularity, we match these to nine observable time series for each of our sample countries: Australia, Canada and New Zealand. We use quarterly data over the period 1990Q1 to 2005Q3.[6] The time series data are from the IMF's *International Financial Statistics* database, with the exception of Australian and New Zealand CPI inflation series, which were obtained from the Reserve Bank of Australia and the Reserve Bank of New Zealand, respectively. The data we collect (with their corresponding theoretical counterparts in parentheses) are import price inflation in home currency as a proxy for foreign goods inflation ($\pi_{F,t} := p_{F,t} - p_{F,t-1}$), home-US real exchange rate (q_t), the 'terms of trade' constructed as the ratio of import prices to export prices ($s_t := p_{F,t} - p_{H,t}$), home real GDP (y_t), home CPI inflation (π_t), home nominal

[6] The Reserve Bank of New Zealand officially began targeting inflation in February 1990 and Canada followed one year later. The Reserve Bank of Australia suggests that inflation targeting was officially adopted in the first half of 1993. However, Bernanke et al. (1999) note that Australian interest rates rose dramatically in the late 1980s with no noticeable increase in inflation and conclude the RBA possessed objectives for inflation that predate the announced adoption of inflation targeting. Since we seek to define preferences via the underlying interest rate rule, we define the inflation targeting period in Australia as beginning slightly earlier than some other commentators.

(overnight cash) interest rate (r_t), the US CPI inflation rate from FRED (π_t^*), US output (y_t^*), and the US federal funds rate (r_t^*).

We detrend using the Hodrick-Prescott filter and construct an output gap of deviations of output from this trend. We use the Hodrick-Prescott filter because we pursue a positive rather than a normative description of policy objectives and over our sample period, monetary policy has been driven by an output gap methodology. This is true of Australia (see the small Australian model described in Beechey et al., 2000), Canada (in particular the Quarterly Projection Model, described in Coletti et al., 1996) and New Zealand (see the New Zealand's core policy model, the Forecasting and Policy System, detailed in Black et al., 1997b and for a more recent description of the role of the output gap in policy, Hargreaves et al., 2006). Over the latter part of our sample, output gaps filtered with a multivariate filter have been used, although these measures are not quantitatively dissimilar (see Hargreaves et al., 2006 for example). We also filter the terms of trade and real exchange rate data using the HP filter for similar reasons. As robustness checks, we have repeated the reported exercises using an alternative detrending method. The main conclusions from our model comparison exercises do not change.

4.4 Results

Before we turn to addressing our first empirical question of whether the central banks in question care explicitly about the exchange rate, we will discuss the estimates of parameters in the models themselves and show that the estimates are quite plausible economically. In section (4.4.2) we take up the first main question. In section (4.4.3) we repeat the same exercise under an alternative data de-trending assumption, to ensure that our result is robust to this assumption. In section (4.4.4) we will address the second question of whether these central banks are similar in their policy preferences. Finally, in section (4.5) we highlight the implications of our policy-preferences analysis for reduced-form behavioral policy responses and also compare the result with estimations of a class of Lubik and Schorfheide (2007)-type ad hoc simple rules.

4.4.1 Structural parameter estimates

The estimated prior and posterior density functions on the key structural model parameters for Australia, Canada and New Zealand are displayed in figures (4.1) -(4.3) . Mean estimates, standard deviations, and 95 percent confidence intervals for the posterior estimates are reported in tables (4.3) -(4.5) .

In addition, the tables report summaries of diagnostic tests for convergence of the Markov chains of the parameters. The convergence test statistics were computed by taking a subsequence of the total 2 million draws, with a length of 0.5 million draws, to reduce computational burden. The NSE in the fifth column refers to the numeric standard error as an approximation to the true posterior standard error described in Geweke (1999). The p-values in the sixth column refer to the equality test between the means calculated using the first and second half of the chain. In each of the models, there are only one or two parameters that did not satisfy the equality test at the 5 percent level. None of the test statistics are significant at the 1 percent level and there is no obvious pattern to which coefficients fail the equality test.

The seventh column shows the univariate "shrink factors" using the ratio of between- and within-chain variances as in Brooks and Gelman (1998). A shrink factor close to 1 is evidence of convergence to a stationary distribution. Almost all of the shrink factors were less than 1.1 and the maximum value across the six models is 1.26. The parameters with a shrink factor greater than 1.1 are those parameters that did not satisfy the 5 percent equality test. Overall, the evidence suggests that the Markov chains have converged to their stationary distribution.

4.4.1.1 Australia

The marginal posterior density estimates for the key parameters for Australia are displayed in figure (4.1) for the case where the central bank is restricted to put no weight on exchange rate variability.

The full set of model estimates is reported in tables (4.2) for model M_1 and table (4.3) for model M_2. Our posterior mean estimates of the Calvo-type frequency of price changes are $\widehat{\theta}_H \approx 0.77$ for M_1 and $\widehat{\theta}_H \approx 0.8$ for M_2, and, $\widehat{\theta}_F \approx 0.68$ for M_1 and $\widehat{\theta}_F \approx 0.72$ for M_2, respectively, in the home goods and imported goods sectors. This suggests that in the home goods sector, the average duration that prices remain fixed is between 4.3 to 5 quarters across the two models. Similarly, for the imported goods sector, average prices stay the same for 3 to 3.6 quarters on average. The "backward-lookingness" in the Phillips curves, represented by δ_H and δ_F, is quite low, especially, for the imported goods sector. The high degrees of price stickiness imply that inflation is not very sensitive to changes in marginal cost (or LOP gap) movements, and therefore, a smaller and slower transmission of monetary policy to inflation.

In contrast, consumption is very sensitive to real-interest-rate changes because the estimate of σ, the coefficient of relative risk aversion, is quite close to 1. The degree of habit persistence is quite high, $\widehat{h} \approx 0.9$. This has the opposite effect on the sensitivity of consumption to real-interest-rate changes. The uniform within-sector demand elasticity of substitution estimate is $\widehat{\eta} \approx 0.36$ (M_1) or $\widehat{\eta} \approx 0.17$ (M_2). This is lower than typical calibrations. For example, Monacelli (2005) sets $\eta \approx 1.6$. A low η implies π_H or domestic output gap is not very sensitive to terms of trade movements compared to usual calibrations, all else equal. The inverse labour supply elasticity is $\widehat{\phi} \approx 1.5$.

4.4.1.2 Canada

The marginal posterior density estimates for the key parameters for Canada are displayed in figure (4.2) . The full set of model estimates is reported in table (4.4) for model M_1 and in table (4.5) for model M_2.

Notable exceptions for Canada's results are that the degrees of backward-looking behavior in firms' pricing are much higher than the estimates for Australia. Here we have δ_H and δ_F estimated in the order of 0.65 and 0.8 respectively.

4.4.1.3 New Zealand

The marginal posterior density estimates for the key parameters for New Zealand are displayed in figure (4.3) for the case where $\mu_q = 0$. The full set of model estimates are reported in table (4.6) for model M_1 and table (4.7) for model M_2.

The private sector deep parameters in New Zealand are quite similar to Australia with the notable exception that the uniform within-sector demand elasticity of substitution estimate of $\widehat{\eta} \approx 1$ is much higher than in Australia or Canada. This implies a greater elasticity of substitution of consumption between home and foreign goods in the model. It also implies that New Zealand's output gap will be very responsive to terms of trade movements.

4.4.2 Are the central banks concerned about "exchange rate volatility"?

Our first empirical question asks whether these flexible inflation-targeting central banks care about the real exchange rate explicitly. Consider two competing models of central banks for a dataset y. Denote a flexible inflation targeter with one-period payoff summarized by (4.44) as $M_1 := \{\Theta : 0 < \mu_q \in \Theta\}$. Let the alternative central bank that does not target exchange rate deviations be given by $M_2 := \{\Theta : 0 = \mu_q \in \Theta\}$.

Table (4.8) summarizes our model comparison based on the posterior odds ratio or Bayes factor, which in our case, is the ratio of the marginal likelihoods of the two competing models. The marginal likelihood of each model for a given data set is numerically computed using the modified harmonic mean estimator in Geweke (1999). For each of the three countries, there is a "better fit" of the data for model M_2 than M_1. For example, consider Canada which has the lowest Bayes factor of 2.97×10^4 across the three economies. In order to infer that the Bank of Canada explicitly targets exchange rate volatility (M_1), one would need to have a prior belief on M_1 which is $2,970$ times stronger than one's prior belief on M_2. Our result in favour of M_2 is corroborated by the observation that the posterior densities of μ_q, in the case of model M_1, estimated for all three countries is very tightly centered around a positive number close to zero. Our result suggests that these small open economy inflation targeters do not explicitly target exchange rate fluctuations via their interest rate decisions.

4.4.3 Robustness of result

We also ensure that the previous model comparison result is not an artifact of our data de-trending assumption. We report an alternative set of results, summarized in Table (4.9) , which assumes that the cyclical components of the output gap, the terms of trade, the real exchange rate, and consumption are constructed by removing a linear trend from each series. For each of the three countries, there is a "better fit" of the data for model M_2 than M_1.

4.4.4 Central banks' objectives and similarities

In this section we address the second empirical question of what are the features of these central banks' preferences and whether they are similar in a statistical sense. More precisely, we will be looking at the "degree of overlap" between the marginal posterior distributions, and also the joint posterior distributions, on their preference parameters.

Inspection of the results displayed in tables (4.2) -(4.8) , reveal that the following features drive central bank objectives in Australia, Canada and New Zealand. First, these central banks care a lot about smoothing interest rate movements. Second, there is not a lot of weight placed on the output gap, a result consistent with a strong inflation targeting focus for these central banks. Finally, these central banks place virtually no weight on exchange rates.

Cross-country comparisons of the preference parameters reveal whether our three open economy inflation targeters possess similar objectives. Figure (4.4) graphs the posterior distributions of both the output stabilization parameter and the interest rate smoothing parameter for each country on the same axes. The degree to which each country shares similar stabilization objectives is illustrated by the degree of similarity between the posterior distributions.

To measure the closeness of two distributions, DeJong et al. (1996) construct a metric using the Confidence Interval Criterion (CIC). The CIC is:

$$CIC_{ij} = \frac{1}{1-\gamma}\int_{a}^{b} P_j(s_i)ds_i \tag{4.48}$$

where $P_j(s_i)$ is the distribution of the simulated model statistic and s_i, $i = 1, ..., n$, are the distributions of interest where $a = \frac{\gamma}{2}$ and $b = 1 - a$ are particular quantiles of a reference distribution $D(s_i)$ the tails of which are truncated by the parameter γ. This implies that the CIC is in fact bounded by 0 and $(1-\gamma)^{-1}$ (such that the CIC is only bounded between 0 and 1 for the special case when $\gamma = 0$). The CIC statistic can be thought of as measuring the overlap in two distributions.

A CIC statistic close to the upper bound $(1-\gamma)^{-1}$, implies the distributions are very similar. A CIC close to zero implies the distributions are not particularly similar because either the location of the distributions is different or the reference distribution is particularly diffuse.

DeJong et al. (1996) advocate using the following measure as a test for any difference in location of the distributions:

$$d_{ji} = \frac{EP_j(s_i) - ED(s_i)}{\sqrt{var(D(s_i))}} \tag{4.49}$$

such that a large difference in expected values (and hence expected location) generates a large test statistics while diffusion in the reference distribution $D(S_i)$ reduces the test statistic.

Inspecting figure (4.4) , the output stabilization parameter in the top half of the figure shows that all three countries place some weight on output stabilization. Canada appears to put the least weight on output stabilization with the left-most posterior distribution with a posterior mode of 0.147. The corresponding distribution for New Zealand is very similar in both shape and location, with a posterior mode of 0.217. With $\gamma = 0.1$ the CIC returns a value of 0.864, indicating that Canada and New Zealand share a similar concern for output stabilization. The Australian posterior distribution places a higher weight on output stabilization with a posterior mode of 0.384. The CIC between Australia and Canada is much smaller – 0.186 although the CIC returns a statistic of 0.475 for the overlap between output stabilization in Australia and New Zealand.

The panel in the bottom half of figure (4.4) shows the overlap of the preference for interest rate smoothing across the three countries. All three countries show some interest rate smoothing behavior. Australia appears to place the least weight on smoothing the interest rate, returning a posterior model of 0.493 while the corresponding parameter is 0.647 for Canada and 0.732 for the case of New Zealand. However, the CIC statistics emphasize similarities rather than differences. The overlap in preferences for smoothing interest rates is 0.830 between Australia and Canada, 0.829 for Australia and New Zealand, and 1.0364 for Canada and New Zealand (which is greater than one since $\gamma = 0.1$, implying $(1-\gamma)^{-1} \approx 1.1$).

A natural question is whether the overall macroeconomic objectives of each country are identical. This is a joint test of whether the distribution of the preferences for macroeconomic stabilization and interest rate smoothing are the same. Rather than averaging the CIC criterion across the preference parameters, we construct a multivariate version of the CIC by generating a three dimensional histogram of joint draws from the posterior. For convenience we set $\gamma = 0$ and compare the volumes generated by integrating over the preference parameters for each country. We use 500,000 draws from the posterior and use a total of 625 bins to characterise the joint distribution.

This joint test returns a high degree of similarity across the distributions. Between Australia and Canada, we find that 90.6 percent of the draws can be characterised by the same distribution; and this figure remains high between Australia and New Zealand (93.4

percent) and between Canada and New Zealand (94.3 percent). Thus our results indicate that the preferences of these three small open economy inflation targeters are, in fact, pretty similar.

4.5 Implications for reduced-form simple policy rule analyses

In this section, we provide the link between our empirical analysis of uncovering what central bank *preferences* are and the resulting implication for policy *behavior*. While it is straightforward to derive the mapping from preferences to equilibrium behavior for the central banks, the converse is not the case, if one begins the analysis from an ad-hoc *behavioral rule*. Thus analyses, such as Lubik and Schorfheide (2007), may not be very informative if one wishes to ask the sort of question we addressed in the previous sections.

The estimated Markov-perfect equilibrium in each of the models reported in Tables (4.2) to (4.7) implies a reduced-form optimal monetary policy decision rule.[7] In this section we show that our estimates across all sample data sets imply reduced-form policy rules that respond to exchange rate movements. This result remains, even in the case when the central bank has no explicit concern for stabilizing the exchange rate in its loss function. To conserve space, we only report the example from Australia.

A representation of the resulting (mean or median) Markov-perfect equilibrium rule for Australia, when $\mu_q > 0$ can be expressed as:

$$\begin{aligned} r_t = 0.16r_{t-1} - 0.11c_t + 0.04\pi_{F,t} - 0.05\pi_{H,t} - 0.23q_t - 0.01s_t - 0.11y_t - 0.01\pi_t \\ + 0.01\tilde{\pi}_t - 0.03\pi_{t-1} + \mathbf{P}_{2,s}((1-\alpha)0.74)^{-1}[\Delta\psi_{F,t} - \Delta e_t - \pi_t^* + \pi_t] \\ + \textit{other exogenous terms}. \end{aligned} \tag{4.50}$$

where $\mathbf{P}_{2,s} \approx -0.04$ and $\alpha = 0.4$.[8]

[7] The full set of results, computational method, and further discussions can be found in a Supplementary Appendix to this paper.

[8] The variable associated with the parameter $\mathbf{P}_{2,s}((1-\alpha)0.73)^{-1}$ comes from the terms-of-trade growth identity in equation (4.39) in the paper, repeated here as:

$$s_t - s_{t-1} = \pi_{F,t} - \pi_{H,t} + \epsilon_{s,t}.$$

From this, and the relationship between terms of trade and the real exchange rate (equation (4.33) in the paper) and the nominal exchange rate (equation (4.32) in the paper), we have the expression, re-written as:

$$\epsilon_s = \frac{1}{1-\alpha}\left[\Delta\psi_{F,t} - \Delta e_t - \pi_t^* + \pi_t\right] - \pi_{F,t} + \pi_{H,t}.$$

The averaged representation for the optimal reduced form policy rule for Australia, when $\mu_q = 0$, has the following form:

$$\begin{aligned} r_t = {} & 0.12r_{t-1} - 0.07c_t - 0.04\pi_{H,t} + 0.02\pi_{F,t} - 0.21q_t - 0.01s_t - 0.07y_t - 0.01\pi_t \\ & + 0.00\widetilde{\pi}_t - 0.03\pi_{t-1} + \mathbf{P}_{2,s}((1-\alpha)0.75)^{-1}[\Delta\psi_{F,t} - \Delta e_t - \pi_t^* + \pi_t] \\ & + \textit{other exogenous terms}. \end{aligned} \tag{4.51}$$

where $\mathbf{P}_{2,s} \approx -0.03$ and $\alpha = 0.4$.

Across all three country data samples, the overall policy response elasticities when $\mu_q = 0$ are quite similar in sign but more attenuated in magnitude to the case when $\mu_q > 0$. This is especially the case, for our response variable of interest: (i) the level of the real exchange rate, (ii) the response to nominal exchange rate growth.

This result shows that behavioral response to exchange rates is not inconsistent with a central bank that has *no* explicit concern for stabilizing movements in the real exchange rate. Furthermore, it provides an optimal policy basis for results found in existing work using ad-hoc Taylor type rules – e.g. Lubik and Schorfheide (2007) – that some central banks do respond to movements in nominal exchange rate growth. That the central banks still respond optimally to exchange rate movements even when $\mu_q = 0$ reflects the endogenous law-of-one-price gap feature of the Monacelli (2005)-style model we use. Monacelli (2005) showed that in a model such as ours, it is no longer sufficient for policy to stabilize a measure of domestic goods price inflation and output gap. There still exists a monetary-policy trade-off arising endogenously from the law-of-one-price gap in imperfect imports price pass-through. This also justifies our assumption, and Monacelli's, of central banks having CPI inflation as an argument in the loss functions. In any case, one could always re-write using equations (4.39) and (4.41), an expression for CPI inflation as

$$\pi_t = \pi_H + \alpha(\Delta s_t - \epsilon_{s,t}),$$

so that the central banks not only care about domestic goods inflation, but also variations to the growth rate in the terms of trade between home and foreign goods.

Therefore, the previous exercise of asking whether central banks *explicitly care* about exchange rate movements, can only be addressed by explicitly modeling and estimating their objective functions. We have shown in this exercise that, given policy preferences, the resulting reduced form policy rule encompasses the results of existing work using ad-hoc Taylor-type rules, in terms of responses to exchange rate movements. However, the reverse analysis, using reduced form rules, may not provide any conclusive evidence for deducing what central banks may care about. In fact, we re-estimate the Lubik and Schorfheide (2007) simple rule in our model, in the following section.

4.5.1 Simple rules and behavioral response

We now take the simple Taylor-type rule used in Lubik and Schorfheide (2007), and re-estimate that in the context of our model and data set (which is defined over more time series variables). This exercise provides a simpler alternative description of central bank behavior. The simple rule specification is:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\psi_\pi \pi_t + \psi_y y_t + \psi_{\Delta e} \Delta e_t) + \varepsilon_t^R, \tag{4.52}$$

where $\rho_r, \psi_\pi, \psi_y, \psi_{\Delta e}$ are the policy responses to the lag of the nominal interest rate, inflation, the output gap and the change in the nominal exchange rate respectively, and ε_t^R is an exogenous policy shock.

To address the question in Lubik and Schorfheide (2007), we examine two specifications: (i) with the central bank *responding* to the change in the nominal exchange rate (that is, allowing $\psi_{\Delta e} \neq 0$) and (ii) imposing no response to the change in the nominal exchange rate (that is, $\psi_{\Delta e} = 0$). The results from estimation of these simple policy rules are presented in table (4.10) .

Comparison of the log data densities shows evidence that the Reserve Bank of Australia (RBA) responds to changes in the exchange rate. The Bayes factor is 1.78. That is, one would have to place a weight of 1.78 on the RBA not responding to nominal exchange rate growth to find both propositions equally likely). Canada does not respond to the change in the exchange rate (the Bayes factor is 0.03) and New Zealand does respond to the change in the exchange rate (the Bayes factor is 6.25). The Bayes factor for the model comparison exercise in the case of Canada is negligibly small. One might argue for a model of a Bank of Canada operating a simple rule with exchange rate response is just as equally probable as one without.

These results are contrary to Lubik and Schorfheide (2007) who find that Australia and New Zealand do not respond to change in the exchange rate but find some evidence that Canada does respond to changes in the exchange rate. The difference in our result to Lubik and Schorfheide (2007) is not surprising. A key omission from the Lubik and Schorfheide (2007) paper is the lack of an endogenous terms of trade specification and the lack of imperfect pass-through of nominal exchange rate changes into domestic import prices. Lubik and Schorfheide (2007) note:

> One issue is our assumption of exogenous terms of trade movements, another is the lack of imperfect pass-through of nominal exchange rate changes into domestic import prices. Overall model misspecification is of concern as it can lead to biased parameter estimates, prevent identification of the true structural parameters and may imply incorrect model selection.

In addition, there is no endogenous persistence in the Lubik and Schorfheide (2007) Phillips equation. The persistence in inflation is solely driven from the shocks and a Phillips equation is more likely to fit the data (see e.g. Fukac and Pagan, 2008), if one introduces endogenous persistence in the inflation process.

Furthermore, Lubik and Schorfheide (2007) estimate on a longer dataset (from 1983Q1 to 2002Q4 for Australia and Canada and from 1988Q1 to 2002Q4 for New Zealand) that contains information from the pre-inflation targeting period for these countries. It is likely that estimation on a single monetary regime produces tighter estimates than the Lubik and Schorfheide (2007) paper that spans both the pre-inflation targeting era and the inflation-targeting period.

In summary, our result from estimating the simple policy rule of Lubik and Schorfheide (2007) within our model and data set, corroborates the result derived from optimal policy in the previous sections. Specifically, both approaches yield a positive behavioral response of policy to nominal exchange rate growth. However, the simple rule approach is only just that – it cannot tell us more about what might explicitly concern central banks.

4.6 Conclusion

We estimate the macroeconomic policy objectives of the central banks of Australia, Canada and New Zealand within the context of an optimizing DSGE model. Our parameter estimates reveal the objectives of these small open economy inflation targeters. We find key differences in the structural parameters of each economy that imply different behaviour in the setting of monetary policy across countries – even if these countries share identical monetary policy objectives.

We emphasize the similarities rather than the differences in the macroeconomic objectives of the central banks of Australia, Canada and New Zealand. Over the period considered, all three central banks show no concern for mitigating exchange rate volatility as an objective in its own right. However, all three central banks show a substantial concern for interest rate smoothing. The Reserve Bank of Australia shows the most desire to mitigate volatility in the output gap but in all three cases the estimated weight on the output gap is substantially lower than the weight on the deviation of annual inflation from target. Nevertheless, all central banks would be sensibly classified as flexible in their approach to inflation targeting.

We further showed that the resulting optimal policy rule still responds to exchange rate movements, even in the case where the central banks do not explicitly care about exchange rate stabilization. We also estimated a class of simple rules, as in Lubik and Schorfheide (2007), as an alternative representative of central bank behavior. While our results here are opposite to that of Lubik and Schorfheide (2007), they corroborate the exchange rate response result in the optimal policy rules. Furthermore, the difference in our findings relative to Lubik and Schorfheide (2007) confirm their doubts on their own results and their conjecture that a richer model with endogenous terms of trade and imperfect imports price pass through may alter their model comparison results.

Our analysis has important implications for assessing the accountability and transparency of monetary policy. By jointly estimating the parameter estimates conditional on the same DSGE model we can make inferences about objectives conditional on the environment each central bank operates under. Such joint estimates result in very different conclusions relative to uninformed inference based on the unconditional distributions of goal variables such as annual inflation, the output gap, interest rates and the exchange rate. Future work could usefully extend the model to incorporate the potential effects of labour market behavior, credit constraints and policy making under model uncertainty on the estimates of central banks objectives.

Table 4.1: Prior parameter densities for all models.

	Prior mean	2.5%	97.5%	Domain	Density function
h	0.60	0.19	0.93	$(0,1)$	Beta
σ	1.00	0.27	2.19	$\mathbb{R}_+$	Gamma
ϕ	1.50	1.01	1.99	$\mathbb{R}_+$	Gamma
η	1.00	0.27	2.19	$\mathbb{R}_+$	Gamma
δ_H	0.70	0.25	0.98	$(0,1)$	Beta
δ_F	0.70	0.25	0.98	$(0,1)$	Beta
θ_H	0.50	0.13	0.87	$(0,1)$	Beta
θ_F	0.50	0.13	0.87	$(0,1)$	Beta
a_1	0.50	0.19	0.96	$(0,1)$	Beta
b_2	0.50	0.19	0.96	$(0,1)$	Beta
c_3	0.50	0.19	0.96	$(0,1)$	Beta
ρ_a	0.50	0.13	0.87	$(0,1)$	Beta
ρ_q	0.90	0.23	1.00	$(0,1)$	Beta
ρ_s	0.25	0.01	0.72	$(0,1)$	Beta
μ_q	0.50	0.13	1.07	$\mathbb{R}_+$	Gamma
μ_y	0.50	0.09	1.24	$\mathbb{R}_+$	Gamma
μ_r	0.50	0.09	1.24	$\mathbb{R}_+$	Gamma
σ_H	2.66	0.91	7.32	$\mathbb{R}_+$	Inverse Gamma
σ_F	2.67	0.91	7.33	$\mathbb{R}_+$	Inverse Gamma
σ_a	1.19	0.52	2.66	$\mathbb{R}_+$	Inverse Gamma
σ_q	0.53	0.32	0.87	$\mathbb{R}_+$	Inverse Gamma
σ_s	1.19	0.52	2.66	$\mathbb{R}_+$	Inverse Gamma
$\sigma_{\pi*}$	1.19	0.52	2.66	$\mathbb{R}_+$	Inverse Gamma
σ_{y*}	1.19	0.52	2.66	$\mathbb{R}_+$	Inverse Gamma
σ_{r*}	1.19	0.52	2.66	$\mathbb{R}_+$	Inverse Gamma
σ_r	1.19	0.52	2.66	$\mathbb{R}_+$	Inverse Gamma

1. For $\mu_q = 0$ the prior and posterior distributions will be degenerate at zero.

Table 4.2: Posterior parameters and convergence diagnostics: Australia ($\mu_q \neq 0$).

	Post Mean	Post Std	2.5%	97.5%	NSE	p-value	B-G
β	0.990	0.000	0.990	0.990	0.000	1.000	1.000
α	0.450	0.000	0.450	0.450	0.000	1.000	1.000
h	0.917	0.022	0.871	0.953	0.002	0.234	1.029
σ	0.809	0.259	0.395	1.440	0.045	0.464	1.026
ϕ	1.586	0.245	1.111	2.059	0.011	0.993	1.000
η	0.363	0.101	0.210	0.594	0.012	0.351	1.021
δ_H	0.257	0.101	0.096	0.504	0.013	0.353	1.023
δ_F	0.046	0.027	0.010	0.109	0.001	0.651	1.001
θ_H	0.777	0.026	0.726	0.829	0.003	0.666	1.004
θ_F	0.682	0.036	0.612	0.754	0.004	0.951	1.000
a_1	0.259	0.084	0.113	0.439	0.002	0.041	1.003
b_2	0.719	0.061	0.583	0.822	0.003	0.955	1.000
c_3	0.891	0.059	0.770	1.005	0.001	0.258	1.001
ρ_a	0.809	0.035	0.735	0.870	0.002	0.657	1.001
ρ_q	0.684	0.050	0.576	0.773	0.004	0.832	1.000
ρ_s	0.811	0.049	0.696	0.893	0.004	0.830	1.001
μ_q	0.005	0.003	0.001	0.012	0.000	0.729	1.001
μ_y	0.412	0.156	0.165	0.766	0.021	0.759	1.003
μ_r	0.611	0.186	0.307	0.988	0.028	0.198	1.062
σ_H	1.057	0.317	0.565	1.827	0.031	0.576	1.005
σ_F	4.430	1.629	1.393	7.121	0.288	0.517	1.021
σ_a	5.178	1.021	3.395	7.325	0.162	0.154	1.079
σ_q	0.746	0.123	0.542	1.023	0.009	0.736	1.001
σ_s	5.452	0.543	4.494	6.515	0.061	0.061	1.066
$\sigma_{\pi*}$	0.418	0.043	0.341	0.509	0.001	0.435	1.000
σ_{y*}	0.547	0.071	0.421	0.701	0.002	0.888	1.000
σ_{r*}	0.220	0.021	0.182	0.265	0.000	0.954	1.000
σ_r	0.363	0.051	0.273	0.471	0.002	0.111	1.004

1. The numerical standard error (NSE) as given in Geweke (1999).
2. The p-value is computed using $L = 0.08$ in Geweke (1999).
3. The B-G univariate "shrink factor" as in Brooks and Gelman (1998).

Table 4.3: Posterior parameters and convergence diagnostics: Australia ($\mu_q = 0$).

	Post Mean	Post Std	2.5%	97.5%	NSE	p-value	B-G
β	0.990	0.000	0.990	0.990	0.000	1.000	1.000
α	0.450	0.000	0.450	0.450	0.000	1.000	1.000
h	0.925	0.022	0.876	0.963	0.003	0.899	1.000
σ	1.029	0.241	0.661	1.646	0.036	0.014	1.244
ϕ	1.492	0.261	0.968	1.995	0.016	0.172	1.011
η	0.219	0.097	0.079	0.430	0.014	0.008	1.231
δ_H	0.399	0.162	0.142	0.717	0.021	0.000	1.382
δ_F	0.047	0.025	0.010	0.108	0.001	0.436	1.002
θ_H	0.797	0.026	0.743	0.845	0.003	0.824	1.001
θ_F	0.720	0.035	0.649	0.785	0.005	0.701	1.004
a_1	0.257	0.084	0.110	0.433	0.002	0.984	1.000
b_2	0.750	0.063	0.617	0.861	0.005	0.144	1.022
c_3	0.891	0.060	0.772	1.007	0.001	0.621	1.000
ρ_a	0.728	0.101	0.465	0.847	0.013	0.019	1.197
ρ_q	0.703	0.049	0.602	0.796	0.004	0.719	1.001
ρ_s	0.852	0.048	0.737	0.927	0.006	0.870	1.001
μ_y	0.404	0.354	0.202	1.482	0.021	0.000	1.697
μ_r	0.517	0.153	0.265	0.845	0.022	0.287	1.035
σ_H	2.058	0.994	0.728	4.223	0.167	0.137	1.098
σ_F	1.504	1.290	0.355	5.405	0.168	0.227	1.063
σ_a	6.758	1.105	4.692	8.891	0.167	0.006	1.280
σ_q	0.819	0.121	0.602	1.069	0.009	0.130	1.022
σ_s	5.716	0.661	4.388	7.167	0.086	0.013	1.162
$\sigma_{\pi*}$	0.419	0.043	0.341	0.509	0.001	0.651	1.000
σ_{y*}	0.533	0.071	0.410	0.686	0.002	0.411	1.001
σ_{r*}	0.219	0.021	0.182	0.265	0.000	0.866	1.000
σ_r	0.342	0.042	0.267	0.430	0.001	0.986	1.000

1. The numerical standard error (NSE) as given in Geweke (1999).
2. The p-value is computed using $L = 0.08$ in Geweke (1999).
3. The B-G univariate "shrink factor" as in Brooks and Gelman (1998).

Table 4.4: Posterior parameters and convergence diagnostics: Canada ($\mu_q \neq 0$).

	Post Mean	Post Std	2.5%	97.5%	NSE	p-value	B-G
β	0.990	0.000	0.990	0.990	0.000	1.000	1.000
α	0.450	0.000	0.450	0.450	0.000	1.000	1.000
h	0.912	0.030	0.850	0.966	0.003	0.415	1.010
σ	1.241	0.354	0.557	1.875	0.061	0.409	1.032
ϕ	1.477	0.248	1.009	1.976	0.006	0.057	1.004
η	0.416	0.119	0.206	0.668	0.010	0.443	1.009
δ_H	0.644	0.179	0.227	0.937	0.024	0.221	1.050
δ_F	0.776	0.145	0.423	0.977	0.020	0.546	1.012
θ_H	0.933	0.017	0.901	0.966	0.002	0.099	1.060
θ_F	0.849	0.031	0.785	0.907	0.002	0.407	1.006
a_1	0.266	0.084	0.119	0.442	0.002	0.976	1.000
b_2	0.748	0.064	0.611	0.865	0.003	0.706	1.000
c_3	0.893	0.061	0.770	1.009	0.001	0.566	1.000
ρ_a	0.433	0.151	0.144	0.723	0.022	0.522	1.013
ρ_q	0.704	0.048	0.607	0.795	0.004	0.852	1.000
ρ_s	0.229	0.167	0.011	0.607	0.024	0.122	1.077
μ_q	0.007	0.003	0.002	0.015	0.000	0.511	1.002
μ_y	0.157	0.094	0.033	0.409	0.012	0.891	1.000
μ_r	0.855	0.424	0.186	1.779	0.068	0.014	1.266
σ_H	20.646	1.569	18.025	24.428	0.243	0.270	1.053
σ_F	0.752	0.411	0.287	1.869	0.036	0.431	1.008
σ_a	2.121	1.004	0.584	4.539	0.144	0.590	1.009
σ_q	0.841	0.111	0.640	1.077	0.008	0.659	1.001
σ_s	2.271	0.369	1.584	3.014	0.035	0.296	1.017
$\sigma_{\pi*}$	0.367	0.040	0.296	0.452	0.000	0.964	1.000
σ_{y*}	0.533	0.071	0.406	0.687	0.002	0.651	1.000
σ_{r*}	0.222	0.022	0.183	0.269	0.000	0.102	1.000
σ_r	0.360	0.045	0.281	0.457	0.001	0.726	1.000

1. The numerical standard error (NSE) as given in Geweke (1999).
2. The p-value is computed using $L = 0.08$ in Geweke (1999).
3. The B-G univariate "shrink factor" as in Brooks and Gelman (1998).

Table 4.5: Posterior parameters and convergence diagnostics: Canada ($\mu_q = 0$).

	Post Mean	Post Std	2.5%	97.5%	NSE	p-value	B-G
β	0.990	0.000	0.990	0.990	0.000	1.000	1.000
α	0.450	0.000	0.450	0.450	0.000	1.000	1.000
h	0.906	0.030	0.851	0.964	0.003	0.290	1.015
σ	1.285	0.338	0.578	1.875	0.055	0.175	1.075
ϕ	1.456	0.254	0.961	1.952	0.006	0.036	1.004
η	0.476	0.114	0.268	0.704	0.009	0.812	1.001
δ_H	0.657	0.177	0.237	0.929	0.023	0.129	1.084
δ_F	0.873	0.082	0.684	0.989	0.007	0.146	1.026
θ_H	0.922	0.016	0.891	0.952	0.001	0.367	1.009
θ_F	0.852	0.037	0.760	0.905	0.003	0.039	1.088
a_1	0.265	0.084	0.119	0.443	0.001	0.670	1.000
b_2	0.718	0.066	0.578	0.840	0.003	0.552	1.001
c_3	0.897	0.059	0.775	1.011	0.001	0.897	1.000
ρ_a	0.366	0.137	0.120	0.639	0.016	0.530	1.009
ρ_q	0.731	0.044	0.640	0.812	0.003	0.720	1.001
ρ_s	0.257	0.180	0.012	0.658	0.025	0.583	1.009
μ_y	0.147	0.069	0.049	0.313	0.006	0.941	1.000
μ_r	0.672	0.233	0.248	1.106	0.033	0.061	1.110
σ_H	20.462	3.145	13.842	24.834	0.545	0.214	1.081
σ_F	0.682	0.490	0.277	2.347	0.033	0.197	1.036
σ_a	2.397	1.618	0.774	6.779	0.221	0.169	1.085
σ_q	0.780	0.104	0.600	1.004	0.004	0.568	1.001
σ_s	2.154	0.362	1.448	2.856	0.039	0.712	1.002
$\sigma_{\pi*}$	0.368	0.040	0.297	0.453	0.000	0.755	1.000
σ_{y*}	0.546	0.073	0.419	0.704	0.001	0.073	1.002
σ_{r*}	0.220	0.021	0.183	0.266	0.000	0.409	1.000
σ_r	0.315	0.035	0.252	0.389	0.001	0.787	1.000

1. The numerical standard error (NSE) as given in Geweke (1999).
2. The p-value is computed using $L = 0.08$ in Geweke (1999).
3. The B-G univariate "shrink factor" as in Brooks and Gelman (1998).

Table 4.6: Posterior parameters and convergence diagnostics: New Zealand ($\mu_q \neq 0$).

	Post Mean	Post Std	2.5%	97.5%	NSE	p-value	B-G
β	0.990	0.000	0.990	0.990	0.000	1.000	1.000
α	0.450	0.000	0.450	0.450	0.000	1.000	1.000
h	0.785	0.040	0.729	0.896	0.004	0.195	1.060
σ	1.568	0.396	0.822	2.257	0.070	0.186	1.085
ϕ	1.550	0.247	1.053	2.028	0.013	0.654	1.001
η	1.011	0.329	0.421	1.683	0.041	0.805	1.001
δ_H	0.175	0.074	0.055	0.338	0.006	0.761	1.001
δ_F	0.087	0.045	0.020	0.193	0.003	0.483	1.003
θ_H	0.775	0.029	0.711	0.825	0.004	0.786	1.002
θ_F	0.697	0.021	0.649	0.729	0.002	0.004	1.171
a_1	0.237	0.085	0.100	0.422	0.002	0.104	1.004
b_2	0.698	0.050	0.587	0.791	0.004	0.310	1.013
c_3	0.890	0.060	0.770	1.007	0.001	0.187	1.001
ρ_a	0.544	0.187	0.165	0.830	0.031	0.625	1.011
ρ_q	0.695	0.039	0.596	0.760	0.004	0.576	1.006
ρ_s	0.682	0.068	0.547	0.827	0.006	0.952	1.000
μ_q	0.006	0.005	0.001	0.018	0.000	0.965	1.000
μ_y	0.273	0.138	0.100	0.623	0.020	0.574	1.010
μ_r	0.850	0.252	0.312	1.221	0.034	0.007	1.287
σ_H	2.100	1.298	0.579	4.984	0.230	0.984	1.000
σ_F	0.775	0.362	0.307	1.647	0.031	0.032	1.064
σ_a	20.023	1.870	15.376	22.747	0.277	0.003	1.368
σ_q	0.800	0.135	0.590	1.122	0.015	0.723	1.003
σ_s	2.656	0.471	1.858	3.689	0.045	0.093	1.056
$\sigma_{\pi*}$	0.412	0.043	0.335	0.503	0.000	0.924	1.000
σ_{y*}	0.553	0.073	0.423	0.708	0.002	0.177	1.003
σ_{r*}	0.222	0.022	0.184	0.269	0.000	0.049	1.001
σ_r	0.374	0.059	0.268	0.500	0.003	0.486	1.004

1. The numerical standard error (NSE) as given in Geweke (1999).
2. The p-value is computed using $L = 0.08$ in Geweke (1999).
3. The B-G univariate "shrink factor" as in Brooks and Gelman (1998).

Table 4.7: Posterior parameters and convergence diagnostics: New Zealand ($\mu_q = 0$).

	Post Mean	Post Std	2.5%	97.5%	NSE	p-value	B-G
β	0.990	0.000	0.990	0.990	0.000	1.000	1.000
α	0.450	0.000	0.450	0.450	0.000	1.000	1.000
h	0.812	0.036	0.752	0.891	0.005	0.999	1.000
σ	1.312	0.318	0.674	2.015	0.046	0.236	1.062
ϕ	1.586	0.264	1.041	2.082	0.010	0.149	1.011
η	0.917	0.307	0.369	1.553	0.031	0.617	1.005
δ_H	0.173	0.074	0.043	0.324	0.007	0.275	1.019
δ_F	0.083	0.044	0.019	0.190	0.002	0.390	1.004
θ_H	0.767	0.027	0.712	0.819	0.003	0.073	1.074
θ_F	0.683	0.020	0.645	0.725	0.002	0.017	1.095
a_1	0.240	0.079	0.103	0.408	0.002	0.501	1.000
b_2	0.722	0.048	0.612	0.809	0.004	0.414	1.007
c_3	0.891	0.060	0.769	1.006	0.001	0.274	1.000
ρ_a	0.622	0.209	0.101	0.821	0.024	0.005	1.296
ρ_q	0.708	0.035	0.631	0.769	0.003	0.199	1.017
ρ_s	0.717	0.057	0.606	0.830	0.006	0.695	1.003
μ_y	0.217	0.113	0.091	0.534	0.013	0.573	1.006
μ_r	0.732	0.222	0.394	1.322	0.030	0.232	1.058
σ_H	1.325	1.558	0.629	6.497	0.089	0.004	1.348
σ_F	0.909	0.478	0.319	2.141	0.051	0.394	1.012
σ_a	17.959	1.596	15.579	21.365	0.246	0.044	1.164
σ_q	0.794	0.128	0.587	1.097	0.009	0.544	1.003
σ_s	2.633	0.454	1.738	3.530	0.041	0.003	1.114
$\sigma_{\pi*}$	0.412	0.042	0.336	0.501	0.000	0.492	1.000
σ_{y*}	0.546	0.072	0.417	0.702	0.002	0.368	1.001
σ_{r*}	0.222	0.022	0.184	0.269	0.000	0.967	1.000
σ_r	0.338	0.047	0.255	0.441	0.003	0.080	1.018

1. The numerical standard error (NSE) as given in Geweke (1999).
2. The p-value is computed using $L = 0.08$ in Geweke (1999).
3. The B-G univariate "shrink factor" as in Brooks and Gelman (1998).

Table 4.8: Posterior odds model comparison.

Country (Model, M_i)	$p(y\|M_i)$	$\ln \frac{p(y\|M_1)}{p(y\|M_2)}$	**Bayes factor**
Australia ($i = 1$)	-1955.0		
Australia ($i = 2$)	-1941.7	-13.3	5.97×10^5
Canada ($i = 1$)	-1815.6		
Canada ($i = 2$)	-1805.3	-10.3	2.97×10^4
New Zealand ($i = 1$)	-1994.6		
New Zealand ($i = 2$)	-1980.5	-14.1	1.33×10^6

1. $M_1 : \mu_q > 0$ and $M_2 : \mu_q = 0$.
2. Marginal likelihood for Geweke's $p = 0.1$ are reported, where $p \in (0, 1)$.
3. The Bayes factor is calculated as $\frac{p(y|M_2)}{p(y|M_1)}$.
4. These results are robust to alternative detrending methods.

Table 4.9: Posterior odds model comparison under linearly de-trended data.

Country (Model, M_i)	$p(y\|M_i)$	$\ln \frac{p(y\|M_1)}{p(y\|M_2)}$	**Bayes factor**
Australia ($i = 1$)	-2083.8		
Australia ($i = 2$)	-2001.2	-82.6	7.46×10^{35}
Canada ($i = 1$)	-1932.9		
Canada ($i = 2$)	-1909.4	-23.5	1.61×10^{10}
New Zealand ($i = 1$)	-2132.4		
New Zealand ($i = 2$)	-2056.8	-75.6	6.80×10^{32}

1. $M_1 : \mu_q > 0$ and $M_2 : \mu_q = 0$.

2. Marginal likelihood for Geweke's $p = 0.1$ are reported, where $p \in (0, 1)$.

3. The Bayes factor is calculated as $\frac{p(y|M_2)}{p(y|M_1)}$.

Table 4.10: Posterior odds model comparison under the Lubik and Schorfheide (2007) simple rule.

Parameter	Mean	Probability int.		Dist	mean	std. dev
			Australia			
		restricted case: $\psi_{\Delta e} = 0$, log data density -1371.422				
ρ_R	0.698	0.630	0.769	Beta	0.5	0.2
ψ_π	2.077	1.771	2.372	Gamma	1.5	0.3
ψ_y	0.342	0.246	0.437	Gamma	0.5	0.1
		unrestricted case, log data density -1370.844				
ρ_R	0.710	0.656	0.769	Beta	0.5	0.2
ψ_π	2.080	1.847	2.320	Gamma	1.5	0.3
ψ_y	0.339	0.253	0.414	Gamma	0.5	0.1
$\psi_{\Delta e}$	0.009	0.000	0.023	Uniform	-0.5	0.5
			Canada			
		restricted case: $\psi_{\Delta e} = 0$, log data density -1219.062				
ρ_R	0.768	0.736	0.798	Beta	0.5	0.2
ψ_π	1.322	1.226	1.430	Gamma	1.5	0.3
ψ_y	0.296	0.208	0.379	Gamma	0.5	0.1
		unrestricted case, log data density -1222.524				
ρ_R	0.741	0.689	0.794	Beta	0.5	0.2
ψ_π	1.253	1.194	1.318	Gamma	1.5	0.3
ψ_y	0.233	0.181	0.287	Gamma	0.5	0.1
$\psi_{\Delta e}$	0.002	0.002	0.002	Uniform	0	0.5
			New Zealand			
		restricted case: $\psi_{\Delta e} = 0$, log data density -1447.368				
ρ_R	0.674	0.601	0.749	Beta	0.5	0.2
ψ_π	2.017	1.619	2.448	Gamma	1.5	0.3
ψ_y	0.393	0.273	0.515	Gamma	0.5	0.1
		unrestricted case, log data density -1445.536				
ρ_R	0.666	0.592	0.742	Beta	0.5	0.2
ψ_π	1.940	1.620	2.257	Gamma	1.5	0.3
ψ_y	0.405	0.287	0.525	Gamma	0.5	0.1
$\psi_{\Delta e}$	0.036	0.000	0.079	Uniform	0	0.5

Figure 4.1: Posterior distribution of key parameters: Australia. Prior (dashed) and Posterior (solid).

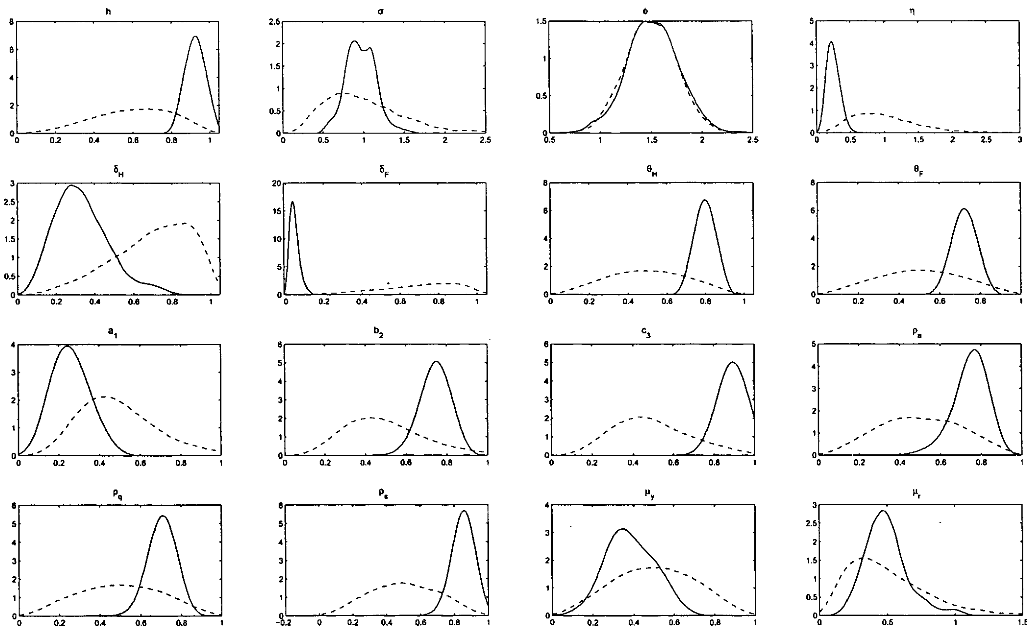


Figure 4.2: Posterior distribution of key parameters: Canada. Prior (dashed) and Posterior (solid).

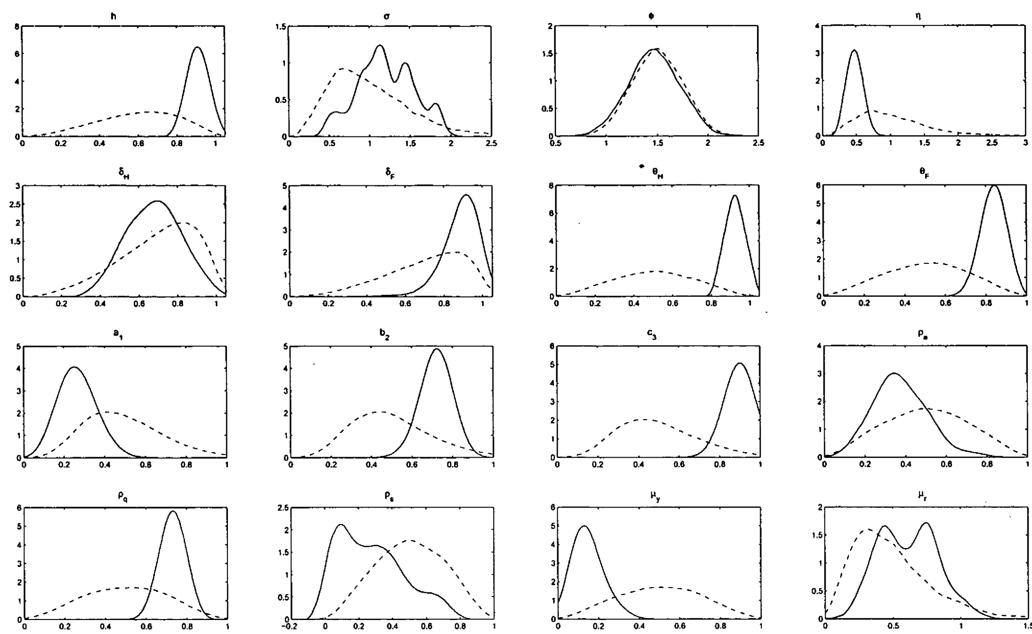


Figure 4.3: Posterior distribution of key parameters: New Zealand. Prior (dashed) and Posterior (solid).

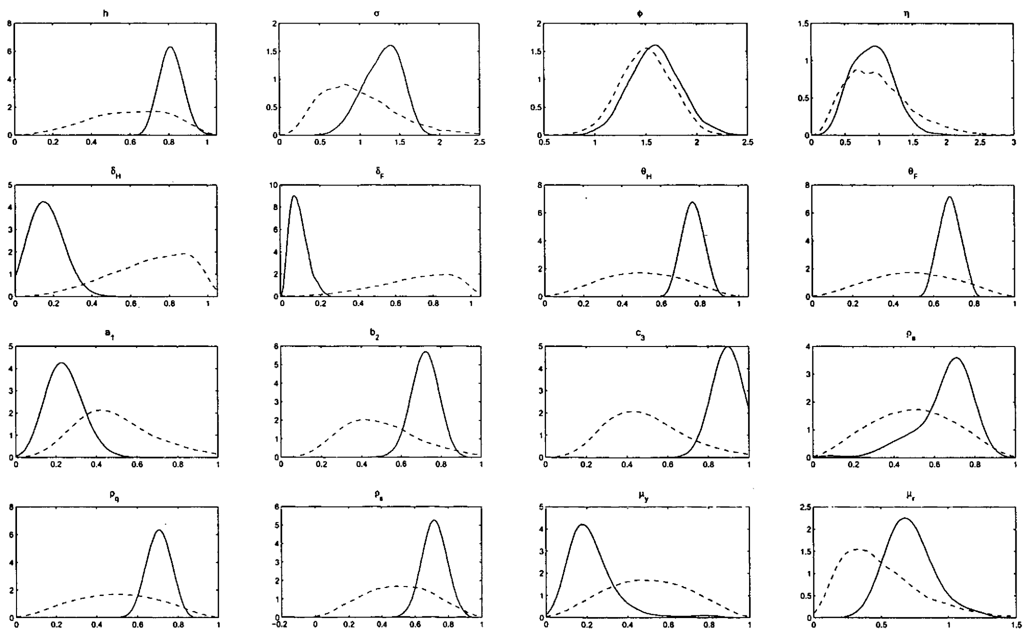
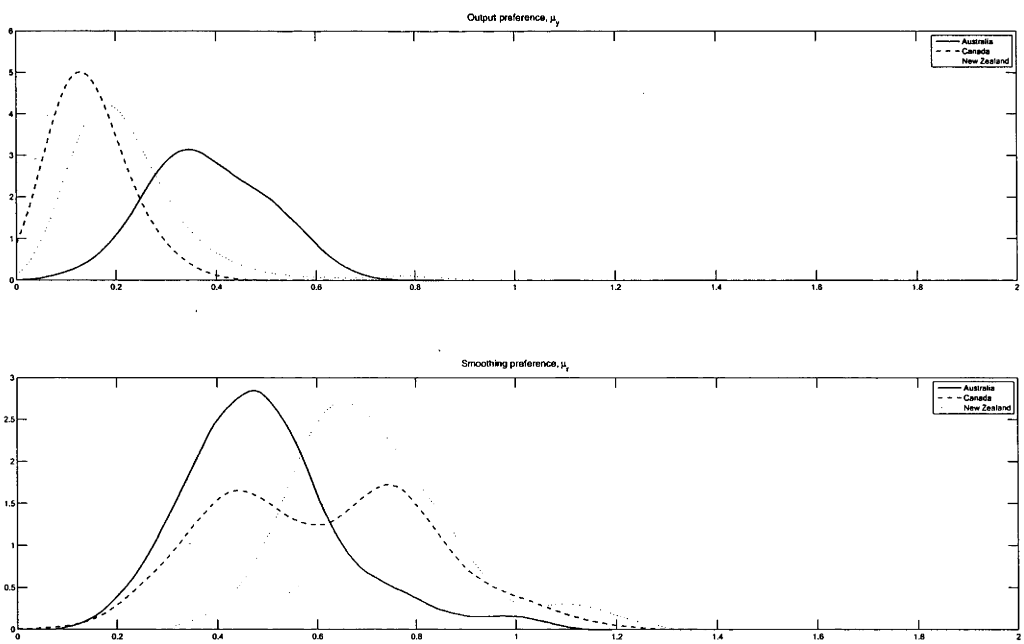


Figure 4.4: Posterior comparison of loss function parameters



4.A Appendix

4.A.1 Log-linear approximations to firms' optimal pricing rule

4.A.1.1 Domestic goods pricing

Given our specific assumption on period utility of households, re-write the first-order condition in (4.23), using the s-period iterate on the Euler operator (4.10) to replace $Q_{t,t+s}$, as

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta\theta_H)^s \frac{(C_{t+s} - H_{t+s})^{-\sigma}}{P_{t+s}} Y_{t+s}(i) \times \left[\widetilde{P}_{H,t} \left(\frac{P_{H,t+s-1}}{P_{H,t-1}} \right)^{\delta_H} - \left(\frac{\varepsilon}{\varepsilon - 1} \right) P_{H,t+s} MC_{H,t+s} \exp\left(\epsilon_{H,t+s}\right) \right] = 0$$

Log-linearize this around the deterministic steady state to obtain

$$\begin{aligned} &\widetilde{p}_{H,t} - \delta_H p_{H,t-1} \\ &\approx (1 - \beta\theta_H) \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\theta_H)^s \left[p_{H,t+s} - \delta_H p_{H,t+s-1} + mc_{H,t+s} + \epsilon_{H,t+s} \right] \\ &= (1 - \beta\theta_H) \left[p_{H,t} - \delta_H p_{H,t-1} + mc_{H,t} + \epsilon_{H,t} \right] \\ &+ \beta\theta_H (1 - \beta\theta_H) \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\theta_H)^s \left[p_{H,t+s+1} - \delta_H p_{H,t+s} + mc_{H,t+s+1} + \epsilon_{H,t+s+1} \right]. \end{aligned}$$

This expression can be written recursively as

$$\widetilde{p}_{H,t} - \delta_H p_{H,t-1} \approx (1 - \beta\theta_H) \left[p_{H,t} - \delta_H p_{H,t-1} + mc_{H,t} + \epsilon_{H,t} \right] + \beta\theta_H \left[\mathbb{E}_t \widetilde{p}_{H,t+1} - \delta_H p_{H,t-1} \right]. \quad (4.53)$$

Log-linearizing (4.19) yields

$$p_{H,t} = (1 - \theta_H) \widetilde{p}_{H,t} + \theta_H p_{H,t-1} + \theta_H \delta_H \pi_{H,t-1}. \quad (4.54)$$

Substituting (4.54) into (4.53) yields the expression (4.24).

Now, equating firms' labor demand (4.22) to households labor supply (4.9):

$$\frac{MC_{H,t} \epsilon_{a,t} P_{H,t}}{P_t} = (C_t - H_t)^{\sigma} N_t^{\varphi} \quad (4.55)$$

Log-linearizing this, and using the log-linearized production function $y_t = n_t + \epsilon_{a,t}$, we have

$$mc_{H,t} = p_t - p_{H,t} + \frac{\sigma}{1-h}\left(c_t - hc_{t-1}\right) + \varphi y_t - \left(1+\varphi\right)\epsilon_{a,t}. \tag{4.56}$$

Utilizing the log-linearized CPI index which implies $p_t - p_{H,t} = -\alpha\left(p_{H,t} - p_{F,t}\right) = \alpha s_t$, and also (4.14), in (4.56) we obtain (4.25).

4.A.1.2 Imports pricing

Re-write (4.30) as

$$\mathbb{E}_t \sum_{s=0}^{\infty} \left(\beta\theta_F\right)^s \frac{\left(C_{t+s} - H_{t+s}\right)^{-\sigma}}{P_{t+s}} Y_{F,t+s}\left(j\right)$$
$$\times \left[\widetilde{P}_{F,t}\left(\frac{P_{F,t+s-1}}{P_{F,t-1}}\right)^{\delta_F} - \left(\frac{\varepsilon}{\varepsilon-1}\right)\widetilde{e}_{t+s}P^*_{F,t+s}\left(j\right)\exp\left(\epsilon_{F,t+s}\right)\right] = 0$$

Log-linearizing, and substituting with $\psi_{F,t+s} + \epsilon_{F,t+s} = e_{t+s} + p^*_{t+s}$, we obtain

$$\widetilde{p}_{F,t} - \delta_F p_{F,t-1} \approx \left(1-\beta\theta_F\right)\mathbb{E}_t \sum_{s=0}^{\infty}\left(\beta\theta_F\right)^s \left[p_{F,t+s} + \psi_{F,t+s} + \epsilon_{F,t+s} - \delta_F p_{F,t+s-1}\right].$$

Log-linearize (4.27) to get

$$p_{F,t} = \left(1-\theta_F\right)\widetilde{p}_{F,t} + \theta_F p_{F,t-1} + \theta_F\delta_F\pi_{F,t-1}. \tag{4.57}$$

Making use of the last two expressions yields (4.31).

4.A.2 Pseudo-code for MCMC procedure

Algorithm 1 *The RW-metropolis algorithm for a linear RE model:*

1. *Begin with an initial prior $\theta_0 \in \Theta$ and its corresponding prior density $p\left(\theta_0|M\right)$ for model M.*

2. *Solve the linear RE model to obtain (4.46) and construct observation equation (4.47).*

3. *For each $n = 0, 1, ...N$, Use (4.46)-(4.47), the given data set $y = \{y^o_t\}_{t=0}^T$, and θ_n to compute the model likelihood, $L\left(\theta_n|y,M\right)$ using a Kalman filter. Then calculate the associated posterior density, $p\left(\theta_n|y,M\right) = \frac{p(\theta_n|M)L(\theta_n|y,M)}{\int_\Theta p(\theta_n|M)L(\theta_n|y,M)d\mu(\theta_n)}$.*

4. *Generate a new candidate draw using a random walk model:* $\theta_{n+1} = \theta_n + z_{n+1}$, *where we assume* $z_{n+1} \sim N(0, s\Sigma)$, *and* $s > 0$ *is a scalar factor for scaling the size of the jump in the draws. Compute the associated posterior density,* $p(\theta_{n+1}|y, M)$ *by repeating Step 3, for* θ_{n+1}.

5. *Compute the acceptance probability,* $\alpha(\theta_n, \theta_{n+1}|y) := \min\left\{\frac{p(\theta_{n+1}|y,M)}{p(\theta_n|y,M)}, 1\right\}$.

6. *Repeat Steps 3-4 for* N *sufficiently large to ensure that the sequence* $\{\theta_n\}_{n=0}^{N}$ *is drawn from an ergodic distribution,* π.

7. *Under some sufficient conditions, we can apply the ergodic theorem of an irreducible Markov chain and approximate the posterior expected value of a (bounded) function of interest,* $f(\theta)$ *using the sample mean of the functions,* $N^{-1}\sum_n^N f(\theta_n)$.

CHAPTER **5**

THE ROLE OF INTERNATIONAL SHOCKS IN AUSTRALIA'S BUSINESS CYCLE

Abstract*

This paper examines the sources of Australia's business cycle fluctuations. The cyclical component of GDP is extracted using the Beveridge-Nelson decomposition and a structural VAR model is identified using robust sign restrictions derived from a structural small open economy model. In contrast to previous VAR studies, international factors are found to contribute to over half of the output forecast errors whereas demand shocks have relatively modest effects.

5.1 Introduction

THERE IS little consensus on the role played by the rest of the world in a small open economy's business cycle. In the case of Australia, Dungey (2002) estimates a structural vector autoregression (SVAR) model, which implies that international factors account for 32 per cent of output forecast errors over a one year horizon, while domestic GDP shocks remain the dominant contributor. A SVAR model for Australia by Brischetto and Voss (1999) reveals that only around 5 per cent of output forecast errors stems from foreign factors. On the other hand, using an estimated New Keynesian dynamic stochastic general equilibrium (DSGE) model, Nimark (2007) concludes foreign shocks explain over 50 per cent of the variance in Australian output around its trend while domestic output shocks account for

*Chapter (5) was previously published as "The Role of International Shocks in Australia's Business Cycle", RBA Research Discussion Papers, RDP2008-08.

only 8 per cent. Using a different criteria, Dungey and Pagan (2000) simulate data from a SVAR model and find that recessions would have been less severe in the absence of foreign disturbances, while cumulated movements during the expansion phrase would also have been smaller.

This paper argues that the different findings of the studies cited above can be understood as resulting from the difficulty of deciding how to appropriately identify the structural disturbances relevant to a small open economy. Identifying restrictions for SVAR models may introduce substantial misspecifications that could lead to invalid inference. At the same time, identification of structural disturbances by means of cross-equation restrictions from a small DSGE model may be a too stringent method to capture the complex dynamics of the data generating process. This paper contributes to this debate by developing a VAR model of the Australian economy using robust sign restrictions derived from an estimated DSGE model. One key element of this approach is that it allows for a theoretically consistent view of the relationships between the set of macro variables without imposing the full DSGE structure.

Earlier sign restriction VAR studies focus mainly on identifying a subset of structural disturbances, examples include Faust (1998) and Uhlig (2005) who identify only monetary policy shocks. More recent studies by Canova and De Nicolo (2002) and Peersman (2005) apply the sign restriction methodology to identify all shocks in the VAR model. All these studies, however, are based on large economies with little discussion of the role of exchange rates. One exception is Farrant and Peersman (2006), who investigate the role of exchange rates in an open economy setting. However, the role of international factors is not explicitly discussed in that study.

The use of restrictions derived from a theoretical model to aid VAR estimation is not new. McKibbin et al. (1998) use the McKibbin-Sachs Global (MSG2) model to restrict the long-run behaviour of a VAR, while the short-run features are left unrestricted. Dungey and Pagan (2009) try to reconcile their earlier SVAR model with restrictions implied by a simple open economy DSGE model. Peersman and Straub (2004) use a calibrated real business cycle (RBC) model to derive sign restrictions in order to identify technology shocks.

The starting point of this paper is to use the Beveridge-Nelson decomposition to extract the cyclical component of GDP, which will be used as a measure of Australia's business cycle. A slightly modified version of the small open economy model proposed in Monacelli (2005), and Gali and Monacelli (2005) is then estimated using maximum likelihood. The estimated model is used to determine a set of robust sign restrictions for the VAR analysis. The small open economy assumption is imposed on the VAR model by restricting the impact of domestic variables on foreign variables. The ultimate aim of the analysis is to map the set of statistical relationships estimated from the reduced form VAR back into a set of structural disturbances for economic interpretation. To do this, an algorithm similar to that proposed by Canova and De Nicolo (2002) is used to trace out all possible orthogonal vector moving average (VMA) representations of the VAR that are consistent with the sign restrictions derived from the estimated DSGE model. Since there is not enough information to uniquely identify a set of structural disturbances, the median impulse approach suggested in Fry and Pagan (2005) is used to summarise the results.

The analysis reveals several interesting results. First, the Beveridge-Nelson decomposition produces a plausible measure of Australia's output fluctuations. The characteristics of the cyclical behaviour match previous business cycle studies using factor models such as Gillitzer et al. (2005). Second, in contrast to previous SVAR studies for Australia, foreign factors account for over half of the output forecast errors whereas innovations from output itself have only a modest effect. The result is robust across different foreign specifications using data for the United States and the Group of Seven (G7) Countries.

The rest of the paper is organised as follows. Section (5.2) describes the Beveridge-Nelson decomposition used to extract the cyclical component of GDP. Section 3 outlines the estimated small open economy DSGE model together with the data used in the analysis. A set of robust sign restrictions are derived from the estimated DSGE model for the open economy VAR. Section (5.4) describes the estimation and identification of the open economy sign restriction VAR model. Section (6.4) summarizes the estimation results. Finally, Section (6.5) reviews the main findings.

5.2 The cyclical component of GDP

The first step of the analysis of this paper is to obtain a measure of the cyclical component of GDP. The cyclical component is defined as the difference between actual and the permanent component of GDP.[1] The permanent component is exctracted by means of a Beveridge-Nelson (BN) decomposition, which is preferred to one popular alternative, the Hodrick-

[1] The terms permanent component and trend are used interchangeably, as are cyclical component and the cycle. A detailed review of various detrending methods can be found in Canova (1998).

Prescott (HP)-filter as the BN-decomposition allows for correlation between the innovations to the permanent and cyclical components.

A time series y_t with an ARIMA(p,1,q) representation can be decomposed into a permanent (τ_t) and cyclical (c_t) component using the BN decomposition as follows:

$$y_t = \tau_t + c_t \tag{5.1}$$

where $\tau_t = \mu + \tau_{t-1} + \alpha\epsilon_t$ is the unobserved permanent component, which is assumed to follow a random walk with an average growth rate of μ; and $c_t = \phi_p(L)c_t + \psi_q(L)\epsilon_t + (1-\alpha)\epsilon_t$ is a stationary and invertible ARMA(p,q) process, where $\phi_p(0) = 0$ and $\Psi_q(L) = 0$.

Likelihood ratio tests suggest that an ARIMA(2,1,1) model provides the best empirical fit for Australian quarterly real GDP between 1980Q4 and 2006Q1.[2] Figure 5.1 shows that the BN-cycle is more volatile than the cycle derived using the HP–filter (based on the smoothing parameter $\lambda = 1600$). This is particularly so in the first half of the sample[3] which displays more pronounced cycles. The two cycles have a similar peak frequency (estimated using the periodogram) around 17 quarters over the sample, with the BN cycle containing noticeably more high frequency oscillations. Figure 5.1 also shows the coincident (GKR) index of Australian economic activity derived by Gillitzer, Kearns and Richards (2005) using a factor model. This index provides a plausible measure of the Australian business cycle using a large number of macroeconomic variables.

The three series each imply a different underlying model, the aim here is to compare and contrast the different cyclical behaviour across the three detrending assumptions rather than to judge which is the best method to use.[4] For all three series, the two recessions during the early 1980s and 1990s are apparent. The BN-cycle and GKR index coincide with respect to the timing of recessions, suggesting a bottoming out of economic activity around 1983Q1 and 1991Q1. The HP-cycle is a bit slower at picking up the recessions.[5] In addition, the BN-cycle identifies two episodes of weak economic activity over the sample period. The first, in 1986, coincides with Paul Keating's *Banana Republic* remark over concerns about Australia's foreign debt position, a sharp depreciation of the exchange rate

[2] The BN decomposition is computed based on the method suggested by Newbold (1990).

[3] The standard deviation of the BN-cycle is 3.9 per cent compared with 1.4 per cent for the HP-cycle over the whole sample.

[4] Another approach is to explicitly estimate the permanent component using a structural vector error correction model (SVECM) as in Pagan and Pesaran (2008).

[5] The HP filter can be thought of as a two-step filter: in the first step it renders y_t stationary; in the second it smooths the resulting stationary series with asymmetric moving average (MA) weights, which can contribute to a delay in identifying the recessions.

and a downturn in household expenditure. The slowdown of the economy following the end of the Sydney Olympic games and the introduction of the goods and services tax in 2000 is also apparent.

5.3 A Stylised Small Open Economy DSGE Model

This section presents the estimated small open economy DSGE model. The model is based on a slightly modified version of that proposed by Monacelli (2005) and Gali and Monacelli (2005). The key advantage of using this model is due to its simplicity and the model includes the set of variables that are crucial for small open economy studies. It also embeds the key theoretical linkages often found in larger small open economy DSGE models. Variants of the proposed model have been heavily used in other applied macroeconomic research. Recent examples include Lubik and Schorfheide (2007) looking at the role of the exchange rate in the central bank's reaction function and Dungey and Pagan (2009) compare the model structure to their earlier SVAR model (see Dungey and Pagan (2000)).

Del Negro and Schorfheide (2009) argue model misspecification, in a sense that the model imposes invalid restrictions on the moving average representation of the macroeconomic time series, remains the key challenge for using DSGE models in empirical policy studies. Although the specific quantitative predictions of DSGE models maybe questionable, the theoretical linkages embedded in DSGE model remains useful for the understanding of contemporaneous relationships among key macroeconomic variables. This is the key motivation for using some but not all of the DSGE model's predictions in the form of robust sign restrictions. The estimated model is simulated to provide these set of restrictions for the VAR analysis.

The model consists of an open economy IS equation and a Phillips curve incorporating imperfect exchange rate pass-through. The monetary authority sets interest rates according to a Taylor-type reaction function, while the exchange rate depends on the interest rate differential between the domestic and foreign economies. The variables for the rest of the world are taken to be exogenous processes. The open economy IS equation derived from the consumer's optimising problem is:

$$\begin{aligned} y_t &= n_1 y_{t-1} + (1-n_1)E_t y_{t+1} - n_2(r_t - E_t\pi_{t+1}) \\ &+ n_3 E_t \Delta y^*_{t+1} - n_4 z_t + n_5 E_t \Delta\psi_{t+1} \end{aligned} \tag{5.2}$$

where: $n_1, \ldots, n_5$ are parameters;[6] y_t is the aggregate output gap; r_t is the nominal interest rate; π_t is the inflation rate; y_t^* is the foreign output gap; and z_t represents technology disturbances that follow an AR(1) process.[7] $\psi_t = (1-\gamma)s_t - q_t$ can be interpreted as the *law of one price gap* which measures the deviation of the domestic price of imported goods from the world price, where s_t is is the terms of trade, defined as export prices relative to import price, and q_t is the real exchange rate. A non-zero ψ_t implies imperfect exchange rate pass-through to import prices. The backward looking component, y_{t-1}, in the IS equation is motivated by the assumption of habit persistence in consumer preferences.

The open economy New Keynesian Phillips Curve (NKPC) derived by solving the firm's pricing decision can be written as:

$$\pi_t = g_1\pi_{t-1} + (1-g_1)E_t\pi_{t+1} + g_2 y_t + g_3\psi_t + \epsilon_{\pi,t} \tag{5.3}$$

where $\epsilon_{\pi,t}$ represents a cost push shock. The Phillips curve is based on the assumption of monopolistically competitive firms, subject to pricing constraints (Calvo pricing and indexation). If $g_3 = 0$, Equation (5.3) collapses down to a familiar closed economy Phillips curve where inflation dynamics are partly driven by past and expected inflation, in addition to the output gap. The open economy dimension includes the effects from the exchange rate as an important part of the monetary policy transmission process.

The assumption of perfect capital markets yields the standard uncovered interest parity (UIP) condition (which links the expected exchange rate depreciation to the interest rate differential):

$$q_t = E_t q_{t+1} + (r_t - E_t\pi_{t+1})' - \left(r_t^* - E_t\pi_{t+1}^*\right) + U_{q,t} \tag{5.4}$$

where $U_{q,t}$ is a time-varying risk premium that follows an AR(1) process.

The monetary authority is assumed to set the nominal interest rate according to a Taylor rule based on contemporaneous inflation and output as well as an interest rate smoothing term:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\phi_1\pi_t + \phi_2 y_t] + \epsilon_{r,t} \tag{5.5}$$

where $\epsilon_{r,t}$ represents a non-systematic deviation from the reaction function. To complete

[6] It is important to note that without further restrictions, it is not possible to separately identify the parameter η_4 and the variance of the unobserved stochastic shock z_t. However, this will not affect the sign restrictions used for the VAR model.

[7] A positive innovation to technology will increase the potential output of the economy hence has a negative effect on the output gap.

the description of the structural model, the terms of trade s_t, the foreign output gap y_t^*, foreign interest rates r_t^* and foreign inflation π_t^* are assumed to follow exogenous AR(1) processes.

The structural model can be summarised as:

$$A_0 Y_t = A_1 Y_{t-1} + A_2 E_t Y_{t+1} + \epsilon_t \tag{5.6}$$

where $Y_t = [y_t, r_t, \pi_t, q_t, s_t, r_t^*, y_t^*, \pi_t^*, \psi_t, z_t, U_{q,t}]$ is a 11×1 vector containing the state variables of model and $\epsilon_t = [\epsilon_{z,t}, \epsilon_{r,t}, \epsilon_{\pi,t}, \epsilon_{q,t}, \epsilon_{s,t}, \epsilon_{r^*,t}, \epsilon_{y^*,t}, \epsilon_{\pi^*,t}]$ is an 8×1 vector of structural innovations.[8] The solution of the model can be represented as a first order VAR:

$$Y_t = B_1 Y_{t-1} + B_2 \epsilon_t \tag{5.7}$$

5.3.1 Data Description

Data from 1980Q1 to 2006Q1 for the Australian economy is used to estimate the structural model and the VAR.[9] The starting period coincides with previous SVAR studies of the Australian economy including Dungey and Pagan (2000). Quarterly observations on real total GDP (y_t), quarterly headline CPI inflation (excluding interest rates and taxes) (π_t), the (goods and services) terms of trade (s_t), the real exchange rate (q_t), the nominal interest rate (measured by the 90-day bank bill rate) (r_t), US GDP (y_t^*), US CPI inflation quarter-on-quarter (π_t^*) and US nominal interest rate (r_t^*) are sourced from the Reserve Bank of Australia, the Australian Bureau of Statistics and the IMF's International Financial Statistics database.[10]

The cyclical component of GDP for both Australia and the US – that is, the output gap measures – are constructed using the BN decomposition described earlier. Due to the unusual upswing in Australia's terms of trade between 2004 and 2006, this time series is detrended using an HP filter to ensure stationarity of the series.[11] All variables apart from inflation and interest rates enter in logs.

[8] In the numerical simulation and estimation of the model, the structural equation is solved using a solution algorithm described in Uhlig (1995).

[9] The effective sample period is from 1980Q4 to 2006Q1 after differencing and construction of the cyclical component of GDP.

[10] Data for the G7 economies is also taken from the IMF's *IFS* and combined using the following weights: the US (0.49); Japan (0.16); Germany (0.10); the UK (0.07); France (0.07); Italy (0.07); and Canada (0.04).

[11] The HP filter imposes the requirement that the permanent component of the ToT series is an I(2) process, that is the ToT series is subject to shifts in the trend growth rate. The HP filter was used as a simplistic assumption and close examination does reveal a small albeit insignificant upward trend in the growth rate of the ToT.

5.3.2 Estimating the DSGE Model

The parameters of the DSGE model are estimated using constrained maximum likelihood (ML). The likelihood function is computed via the state-space representation of the model's solution in Equation (5.7), together with the measurement equation linking the observed data and the state vector:

$$Z_t = GY_t \tag{5.8}$$

where: Z_t denotes the observed data; and the matrix G specifies the relationship between the state variables and the observed data. The posterior parameter distribution is simulated using the Metropolis Hasting (MH) algorithm described in An and Schorfheide (2007).

The ML estimates are generated conditional on the OLS estimate of the model's four exogenous processes that explain developments in the rest of the world: the terms of trade s_t, foreign inflation π_t^*, interest rates r_t^* and output y_t^*. There are two advantages in estimating the observed exogenous processes independently of the model. First, it reduces the number of parameters to be estimated in the simulation algorithm. Second, Fukac and Pagan (2006) argue that rigid restrictions imposed by DSGE models on the data may yield invalid estimates of the model's observable shocks (that is, shocks that are mapped into actual data, such as the foreign output gap y_t^*).

The ML estimate of the model's parameters from the 1.5 million Markov chain draws are summarised in Table 5.1 of the Appendix.[12] The set of Markov chain diagnostic tests imply that the simulated chains attain their stationary distributions.[13] The degree of backward lookingness is estimated to be 0.09 for the IS equation (n_1) and 0.27 for the Phillips curve (g_1). The estimated coefficient on the real interest rate (n_2) in the IS equation is relatively small suggesting output variation is relatively insensitive to interest rate changes. The response of inflation to output gap changes (g_2) is also estimated to be low. The Taylor rule displays a significant degree of interest rate smoothing behaviour with ρ_r estimated to be 0.90. The estimated weight on output is slightly higher than the weight on inflation and consistent with standard calibrated values used in the literature. However, the estimation covers a period before the inflation targeting regime, it is no surprise that there is a wide confidence interval around the Taylor-rule coefficient on output, ϕ_2.

[12] A 50 per cent burn-in is discarded before computing the summary statistics.

[13] There is only one exception, n_4, which is significant at the 5 per cent level. However, a small Brooks and Gelman statistic of 1.12 indicates that the chain has converged.

5.3.3 Qualitative Analysis of the DSGE Model's Impulse Response Functions

This section present the impulse response functions of the model. The IRFs are simulated by sampling the empirical distribution of the estimates of the DSGE model. This takes into account the uncertainty of the responses associated with parameter uncertainty. The median (solid lines) along with the 5th and 95th percentile (dotted lines) responses are shown in Figures 5.2 and 5.3. The IRFs of the model are broadly consistent with other open economy studies based on New Keynesian models. Moreover, the initial responses of key variables are generally quantitatively significant providing a useful set of robust sign restrictions for the VAR analysis. The discussion here will focus more on the initial responses rather than the dynamic adjustments to the shocks.

A positive technology shock will increase the potential output of the economy (τ_t in equation 5.1), because of nominal rigidities actual output will take time to adjust to the new higher potential level of output, the output gap falls. This causes the interest rate to fall. The real exchange rate depreciates to reflect the change in the interest rate differential, which contributes to a small increase in the inflation rate, despite the boost to productivity.

A cost push shock increases inflation, and leads to an increase in interest rates that causes the exchange rate to appreciate and output to contract.

A negative shock to the risk premium causes lower inflation and output, due to an appreciating exchange rate. The central bank responds by reducing the interest rate. An unexpected tightening of monetary policy has a negative effect on the output gap, with lower inflation and an appreciated exchange rate.

Turning to external factors, following a positive shock to Australia's terms of trade, the output gap increases, the real exchange rate appreciates, and inflation and interest rates rise. An exogenous increase in the foreign interest rate leads to a depreciation of the domestic currency, which is sufficient to raise the output gap and together these forces push up inflation. Given the simple structure of the model, an increase in foreign inflation has a similar but opposite effect on the domestic economy as increases in the foreign nominal interest rate. An increase in foreign output actually decreases the domestic output gap, while both domestic inflation and interest rates stay relatively static and the depreciating exchange rate helps balance the international consumption risk sharing condition.[14]

[14]Gali and Monacelli (2005) provide a detailed account of the way in which such a shock can lower domestic potential output.

5.3.4 Robust Sign Restrictions

The focus of the study is to gather a set of sign restrictions from the impulse responses of the DSGE model to identify the structural shocks of a small open economy VAR. The complete set of estimated IRFs from the DSGE model provides more sign restrictions than are necessary to disentangle the eight structural shocks. Bearing in mind the potential misspecification issue, not all the restrictions from the model are imposed upon the VAR. One can think of the set of sign restrictions imposed in the paper as the minimum set of restrictions needed to disentangle the eight shocks. The chosen set of sign restrictions is broadly consistent with restrictions implied by other standard open economy structural models.[15] The set of sign restrictions adopted are presented in Table 5.2.

There are a few important things worth highlighting. First, given that the three foreign variables enter the structural model as exogenous driving processes, the set of sign restrictions imposed on the foreign economy follows the dynamic responses implied by a canonical closed economy New Keynesian model. The responses of the domestic variables to the three foreign shocks are left unrestricted. Second, the terms of trade is treated as an endogenous variable and its response to other shocks apart from the output shock are also left unrestricted.[16] With the presence of sticky home prices in the short run, the terms of trade responds to other variables in the system via changes to domestic inflation. Third, the output shock can be viewed as anything that moves output and interest rates together but is orthogonal to all other shocks in the system. Lastly, the sign restrictions are imposed for the initial two quarters only.

5.4 Estimating a VAR model

This section sets out the small open economy sign restricted VAR model estimated using the data described in Section 6.A.2. An eight-variable VAR(2) is fitted to quarterly observations from 1980Q4 to 2006Q1 where the number of lags are determined by the Akaike Information Criteria.

[15]Additional and/or alternative choices can potentially give different impulse response functions for the VAR, in particular the response to domestic shocks. However, the results of international shocks (the key focus of the paper) should remain fairly robust because there are no explicit restrictions imposed on the domestic economy from international shocks.

[16]The terms of trade is defined here as the domestic currency relative price of exports over imports.

Consider a general VAR(p) model with n variables Y_t:

$$BY_t = A(L)Y_{t-1} + \epsilon_t \tag{5.9}$$

where: $A(L) = A_1L + \cdots + A_pL^p$ is an p^{th} order matrix polynomial; B is an $(n \times n)$ matrix of coefficients that reflect the contemporaneous relationships among Y_t; and ϵ_t is a set of $(n \times T)$ normally distributed structural disturbances with mean zero; and variance covariance matrix Σ, $\Sigma_{i,j} = 0 \; \forall i \neq j$. The structural representation in Equation (5.9) has the following reduced form:

$$Y_t = \Pi(L)Y_{t-1} + e_t \tag{5.10}$$

where $\Pi(L) = B^{-1}A(L)$ and e_t is a set of $(n \times T)$ normally distributed reduced-form errors with mean zero and variance covariance matrix V, $V_{i,j} \neq 0 \; \forall i,j$. The aim is to map the statistical relationships summarised by the reduced form errors e_t back into economic relationships described by ϵ_t. Let $P = B^{-1}$. The reduced form errors are related to the structural disturbances in the following manner:

$$e_t = P\epsilon_t \quad \text{and} \quad V = E(e_te_t') = HH' \tag{5.11}$$

for some matrix H such that $HH' = P\Sigma P'$. An identification problem arises if there are not enough restrictions to uniquely pin down H from the matrix V.[17]

5.4.1 Identification Through Sign Restrictions

The identification of structural shocks is often a controversial issue, with different identifying assumptions leading to quite different conclusions. Typical restrictions employed in the literature are based on restricting the short-run or long-run impact of certain shocks on a subset of variables to be zero. The Choleski decomposition is an example of one such strategy where the contemporaneous impact of shocks follows a recursive ordering. One noticeable feature of standard empirical DSGE models is that they almost never imply zero contemporaneous impacts. This is also the case with the estimated structural model presented in Section 5.3.

The central idea behind structural VAR analysis is to decompose the set of reduced form shocks, characterised by V, into a set of orthogonal structural disturbances characterised

[17] There are n^2 unknowns elements in H with only $n(n+1)/2$ unique elements in V.

by Σ. However, there are an infinite number of ways in which this orthogonality condition can be achieved. Let H be an orthogonal decomposition of $V = HH'$. The multiplicity arises from the fact that for any orthonormal matrix Q (where $QQ' = I$), such that $V = HQQ'H' = \tilde{H}\tilde{H}'$ is also an admissible decomposition of V. This decomposition does not have any economic content, but nevertheless, produces a set of uncorrelated shocks $\epsilon_t = \tilde{H}e_t$, without imposing any zero contemporaneous restrictions.

The identification strategy used here closely follows Canova and De Nicolo (2002), Uhlig (2005), and Peersman (2005) in using qualitative information directly from IRFs to achieve identification. Canova and De Nicolo (2002) proposed an algorithm to trace out all possible orthogonal vector moving average (VMA) representations of the VAR consistent with a given set of sign restrictions. See the Appendix for a more detailed description of the algorithm.

5.4.2 Finding the Median Impulse

The next step is to construct a summary measure from all the VAR representations consistent with the given set of sign restrictions. A common approach is to examine all of the feasible IRFs implied, and report the median response at each horizon for each variable. However, Fry and Pagan (2005) criticise this approach since the implied 'median' IRF may not actually be a feasible response (since it is likely to consist of selected parts of paths implied by different candidate functions). In other words, inference is difficult because the orthogonality condition may be violated.

Fry and Pagan suggest locating a unique identification matrix such that all of the feasible impulses are closest to its median while maintaining the orthogonality condition. Each feasible VAR representation can be distinguished by the rotation angle, θ. So the objective is to choose θ so as to minimise:

$$\Upsilon(\theta_j) = \sum_{i=1}^{q}(\phi_i^j - \bar{\phi}_i)(\phi_i^j - \bar{\phi}_i)' \tag{5.12}$$

where: the index i refers to the horizon for which the impulses are calculated; ϕ_i^j is an $n \times n$ matrix of standardised impulses for the jth rotation; and $\bar{\phi}_i$ is the median impulse over all possible rotations.[18] Full details of the methodology and implementation are provided in the Appendix.

[18] In Fry and Pagan (2005), q is set to 1 focusing only on the initial period impulse.

5.5 Sign-restricted VAR Results

The identification scheme based on the sign-restricted VAR allows for a structural interpretation of the effects of shocks. The impulse response of the output gap, the interest rate, inflation, the real exchange rate and the terms of trade with respect to the three foreign shocks are shown in Figure (5.4). An exogenous increase in the foreign interest rate results in a depreciation of the exchange rate which raises domestic inflation. In contrast to the DSGE model, the depreciation of the exchange rate is more gradual, reaching a peak at 8 quarters before returning to equilibrium. A more important difference from the DSGE results is that output falls, which appears to reflect the decline in foreign output (not shown) and would also help to explain why domestic interest rates decline.

In contrast to the DSGE estimates, the sign-restricted VAR estimates imply that an increase in foreign output leads to a positive domestic output gap, reaching a peak after 4 quarters. The positive domestic output gap implies increased inflationary pressure, which induces a tightening of monetary policy over time to bring both output and inflation back to steady state. The response of the domestic economy following a foreign inflation shock is very similar to that implied by the DSGE model. The exchange rate appreciates in response to the lower real interest rate differential. This leads to a fall in the output gap and subsequently a decline in inflation. There is a small monetary loosening to bring both output and inflation back to equilibrium.

Figures (5.4) and (5.5) display the summary IRFs from the sign-restricted VAR for the remaining five domestic shocks. A positive output shock (that is, a negative technology shock) raises the interest rate consistent with the sign restriction. This shock also induces inflationary pressure and the interest rate remains above its steady state level for some time. An unanticipated tightening of monetary policy lowers both inflation and output while the exchange rate appreciates in response to higher real interest rates. After the shock, the interest rate falls so as to stimulate output and bring inflation back to its steady-state level. Following a positive cost-push shock, the domestic interest rate increases, the exchange rate appreciates and the output gap falls. A negative shock to the risk premium triggers an appreciation of the exchange rate leading to lower inflation. The monetary authority responds to this by lowering the domestic interest rate. In contrast to the structural model, the effect of the monetary response is estimated to outweigh the effect of the higher exchange rate, leading to higher output. A terms of trade shock has a positive effect on both output and inflation leading to a tightening of monetary policy. The exchange rate also responds to the higher terms of trade, helping to stabilise both output and inflation.

The results highlight important differences between the responses of the SRVAR compared with the estimated DSGE model. This further emphasizes Del Negro and Schorfheide's 2009 conclusion that model misspecification remains the key challenge in applied macroeconomic research. However, this is not to say that all the restrictions are invalid, some remain useful especially when the data can not be used to help distinguish competing theories as in the case of exactly identified VARs. Peersman and Straub (2009 forthcoming) use a similar approach to try and disentangle the response of hours worked following a productivity shock in the euro area.

5.5.1 Main Drivers of Output Over the Business Cycle

Variance decompositions are often used to determine the relative contribution of shocks to the forecast error variance of a variable of interest over different horizons. As a benchmark, I first present a variance decomposition based on the Choleski decomposition. The variables are ordered according to the convention that the most exogenous (or predetermined) variables appear first. The variance decomposition results reported in Table (5.3) are based on the following ordering: foreign output, foreign inflation, the foreign interest rate, the terms of trade, the output gap, inflation, the interest rate and the real exchange rate. Investigation of other ordering schemes, where the order of output among the domestic variables varies from first to last, reveals little difference in the variance decomposition results for output. The benchmark results show that at the one-year horizon, shocks to the domestic output gap account for around two thirds of the total variance in the output gap while other domestic factors play only a modest role. Foreign shocks account for just over one quarter of the output gap forecast error variance, with the biggest contributor being foreign output accounting for around 16 per cent. At longer horizons, the role of domestic output shocks decreases slightly while other domestic factors play a slightly larger role. The contribution from all foreign factors stays fairly constant across the different forecasting horizons.

Looking at the variance decomposition of the shocks identified by the sign-restricted VAR model reveals some important differences (Table 5.4). These results suggest that domestic output shocks only account for 4-5 per cent of the variation across all horizons. At the shorter horizons, all three foreign factors combine to account for more than 60 per cent of the output gap forecast error variance. A sizeable share of this appears to be due to foreign monetary policy innovations, although this may, in part, reflect factors that are outside of the model, such as global confidence, that are transmitted to the domestic economy via international financial markets. This view is consistent with the findings in Dungey and Pagan (2000), which shows that international financial linkages are important when modelling the Australian economy. At the longer forecasting horizon, all three foreign factors maintain their influence on domestic output gap variations with both the foreign interest rate and foreign output remaining the dominant contributors. Although the model treats the terms of trade as endogenous, realistically it can be thought of as exogenous, at least over longer horizons. So in this respect the terms of trade could be thought of as another foreign factor. The terms of trade account for a quarter of the variation in output across all but the shortest of horizons. This is consistent with the significance of commodities in Australian exports. Turning to domestic factors, interest rate shocks are estimated to have only a small influence on output gap fluctuations, while inflation (cost-push) and exchange rate (risk premium) shocks each contribute around 5-8 per cent to the variance of the output gap. This is broadly similar to the Choleski baseline results.

One may ask what is the role of foreign factors among other admissible rotations since it is impossible to distinguish them statistically. To check the sensitivity of the variance decomposition results around the optimised median impulse, the chosen median rotation is dropped and the next median impulse is found by re-optimising Equation (20) over the remaining admissible rotations. Repeating this procedure 50 times around the 'median region' reveal foreign factors explains between 45 per cent to 60 per cent of the unconditional variance in output, with foreign interest rates remaining the dominant contributor. To give a more complete picture, Figure 5.6 plots the forecast error variance for the output gap attributed to foreign factors at both the one-year and 50-quarter horizon across all 2000 admitted rotations.[19] The first point to note is that the results presented above lie exactly on the mode of the distribution, while the baseline Choleski decomposition lies in the thin tail of the distribution. Looking at the range of values from the sign-restricted VAR analysis, it appears that the true importance of foreign factors may not be easily captured by Choleski decompositions that impose contemporaneous (zero) coefficient constraints.[20]

[19]The contribution from domestic factors can be easily read off the graphs since the two factors must sum to 100.

[20]Estimating the sign restricted VAR over the shorter sample 1992:Q1 - 2006:Q1 suggests that if anything foreign output shocks have become more important for explaining the variance of the domestic output gap, while shocks to foreign interest rates have become less so. However, this sample may be too short to produce reliable estimates

Variance decompositions may reveal which shocks are important at explaining the forecast errors of output across different horizons. However, Fry and Pagan (2005) argue they may not be very useful in understanding the nature of business cycle fluctuations. One useful statistic is to decompose the historical observation of output into its MA representation in terms of shocks, that is:

$$y_t = \sum_{j=1}^{k} C_j(L)\epsilon_{j,t} + \text{initial condition} \tag{5.13}$$

where $C_j(L)$ is the impulse response to the shock j.[21] Historical decompositions are particularly useful in relating certain events that have happened over the business cycle.

Figure (5.7) plots the historical decomposition of output into foreign (output, inflation and interest rates) versus domestic factors. During the two recessionary periods (the early 1980s and 1990s), both domestic and foreign factors had contributed negatively to output. This observation is consistent with the results reported in Dungey (2002). From the early 1990s onwards, the Australian economy experienced relatively stable and low inflation combined with robust output growth. Coincidentally, foreign and domestic shocks appear to have had offsetting effects so as to moderate domestic business cycle fluctuations during this period. For example, the slowdown in the economy after the Sydney Olympic games together with the introduction of GST in 2000 was somewhat offset by buoyant conditions before the bursting of the 'dot-com' bubble in the US. A buoyant housing market and strong household consumption in the early part of this decade was moderated by a temporary downturn in the US economy following the terrorist attacks in September 2001. The pattern continued in late 2003 where slowing conditions in the Australian housing market were offset somewhat by a relatively strong US economy.

5.5.2 Robustness checks

5.5.2.1 G7 as the Foreign Economy

To check the robustness of these results, the sign-restricted VAR model is re-estimated using G7 data as the foreign economy. It is certainly the case that China has become increasingly more important for the Australian economy, as of 1 October 2009 the RBA

of the relatively high dimensional VAR.

[21] Since the entire history of shocks are not observed, the decomposed components of y_t may not add up exactly for the initial periods of the sample. In the case of output, this is around 6-8 quarters, which are dropped from the decomposition results shown in Figure 6 below.

calculates the share of the Chinese currency in the Trade weighted index (TWI) to be over 16%. However, over a large part of the sample this paper considers, the G7 countries remained as Australia's dominant trading partners. According to the RBA Bulletin (2002), the weight of the Chinese currency in Australia's TWI ranged from 2% in 1980 to 8.5% in 2002, whereas the G7 countries accounted for 77% to 52% over the same period.

The overall conclusion using the G7 dataset is supported although minor differences do arise.[22] The combined contribution of foreign shocks accounts for around 63 per cent of the forecast error variance for the output gap at the one-year horizon, similar to that reported earlier. At the 50-quarter horizon, this increases to 76 per cent in contrast to 59 per cent based on using only US data. Consistent with the earlier estimates, innovations from domestic output play a smaller role in explaining domestic output gap forecast errors. However, within the set of international variables, foreign output now takes on a larger role compared with foreign interest rates. This tends to suggest that interest rates may have been picking up other global factors in the results based on US output alone.

5.5.2.2 Using the HP filter as alternative detrending method

Another important assumption behind the discussions above is that the results are based on cyclical movements extracted from the BN decomposition. As an additional robustness check, the VAR is re-estimated using cyclical movements extracted from the HP filter.

Across all horizons, the three foreign shocks together contribute around 50% of the forecast errors for output, whereas domestic output shocks only account for under 9%. In contrast to the BN decomposition, foreign output shocks are now the dominant contributor at around 30% and foreign inxterest rate shocks around 17%. The results demonstrate that the key determinant of the output forecast error rests with the sign restriction identification.

5.6 Conclusion

This paper uses a small open economy VAR model to investigate the sources of business cycle fluctuations for the Australia economy. The VAR is identified using robust sign restrictions derived from an estimated small structural (DSGE) model. The results suggest that international factors account for over half the domestic output fluctuations while demand

[22]Detail statistics are not reported but are available upon request.

type shocks play a small role. The result appears to be robust to alternative detrending of the data and using different representation as the foreign economy.

The paper tries to address some of the shortcomings in the earlier sign restriction literature that the sign restrictions are arbitrarily imposed by selecting a set of robust sign restrictions from an estimated structural model. However, the analysis does not tackle the question which model is more valid. A monte carlo study would be better place to study the usefulness of sign restrictions and that is left to future work.

Table 5.1: Maximum likelihood estimates of the structural model

Parameters		**MLE statistics**				**Diagnostics**	
	Mean	Std	2.5%	97.5%	NSE	p-value	B-G
$n1$	0.09	0.06	0.01	0.24	0.00	0.06	1.03
$n2$	0.01	0.01	0.00	0.04	0.00	0.75	1.00
$n3$	0.21	0.10	0.05	0.43	0.01	0.54	1.01
$n4$	0.26	0.09	0.15	0.50	0.01	0.02	1.12
$n5$	-0.70	0.16	-1.11	-0.43	0.02	0.56	1.01
$g1$	0.27	0.05	0.16	0.37	0.01	0.93	1.00
$g2$	0.01	0.01	0.00	0.04	0.00	0.09	1.01
$g3$	0.00	0.00	0.00	0.01	0.00	0.24	1.00
ρ_r	0.90	0.02	0.84	0.93	0.00	0.07	1.11
ϕ_1	1.31	0.22	1.02	1.87	0.03	0.24	1.05
ϕ_2	1.56	0.38	0.78	2.30	0.05	0.16	1.09
ρ_z	0.78	0.07	0.62	0.89	0.01	0.22	1.04
ρ_u	0.98	0.01	0.95	1.00	0.00	0.94	1.00
σ_z	2.10	0.16	1.83	2.52	0.02	0.95	1.00
σ_π	1.03	0.22	0.72	1.54	0.03	0.36	1.03
σ_r	1.10	0.08	0.97	1.28	0.01	0.92	1.00
σ_q	1.78	0.13	1.55	2.06	0.02	0.13	1.05
OLS estimates							
ρ_s	0.90						
ρ_{r^*}	0.94						
ρ_{π^*}	0.62						
ρ_{y^*}	0.29						
σ_s	1.75						
σ_{r^*}	1.07						
σ_{π^*}	1.67						
σ_{y^*}	4.14						

1. The posterior statistics are computed based on 1 million MCMC draws after a 50% burn in period.
2. NSE refers to the numerical standard error of the Markov chain.
3. p-value relates to the test of two means between the first and second half of the stationary Markov chain.
4. B-G refers to the Brooks and Gelman (1998) univariate shrink factor. A shrink factor close to 1 is an indication of attaining a stationary distribution.

Table 5.2: SRVAR sign restrictions

	r^*	y^*	π^*	y	r	π	q	s
Foreign interest	↑	–	↓	–	–	–	–	–
Foreign output	↑	↑	–	–	–	–	–	–
Foreign inflation	↑	↓	↑	–	–	–	–	–
Output (composite)	0	0	0	↑	↑	–	–	–
Monetary policy	0	0	0	–	↑	↓	–	–
Cost push	0	0	0	↓	↑	↑	↑	–
Risk premium	0	0	0	–	–	↓	↑	–
Terms of trade	0	0	0	–	↑	↑	↑	↑

1. "–" indicates no restrictions and 0 indicates no contemporaneous impact.

Table 5.3: Baseline Choleski variance decomposition of output, interest, inflation and real exchange rate

Horizon	Foreign interest	Foreign output	Foreign inflation	Output	Interest	Cost push	exchange rate	TOT
				Output				
1	0.3	2.0	7.5	89.0	0.0	0.0	0.0	1.2
4	3.3	15.7	7.5	65.8	0.9	3.5	2.3	1.0
8	3.1	14.8	8.9	62.1	1.9	4.5	3.3	1.4
12	3.0	14.5	9.1	60.1	2.8	5.3	3.7	1.5
50	3.0	14.4	9.1	58.6	3.8	5.8	3.8	1.6
				Interest rate				
1	0.7	0.1	1.2	3.7	90.5	1.6	0.0	2.1
4	1.9	9.8	5.3	17.2	53.7	10.8	0.7	0.7
8	5.1	16.7	4.5	24.9	35.7	12.3	0.3	0.4
12	6.4	19.7	3.7	28.4	29.2	11.5	0.4	0.7
50	8.9	23.0	2.9	29.1	22.5	9.1	1.1	3.4
				Inflation				
1	3.0	0.9	0.1	0.7	0.0	94.9	0.0	0.4
4	2.7	2.4	1.8	0.9	12.1	74.1	4.0	2.0
8	3.7	5.8	2.2	4.4	12.5	64.3	4.2	3.0
12	5.1	8.4	2.0	6.8	11.6	58.2	4.5	3.4
50	7.4	11.7	1.8	8.8	10.3	50.8	4.6	4.6
				Exchange rate				
1	0.7	0.1	0.0	0.1	3.0	0.0	87.8	8.2
4	0.7	0.1	6.8	3.2	2.8	3.9	80.5	2.1
8	4.5	1.2	14.3	2.2	2.8	5.3	68.0	1.7
12	9.3	2.8	17.6	1.7	6.5	5.3	55.1	1.7
50	11.7	4.0	17.0	1.8	13.5	5.4	44.6	2.0

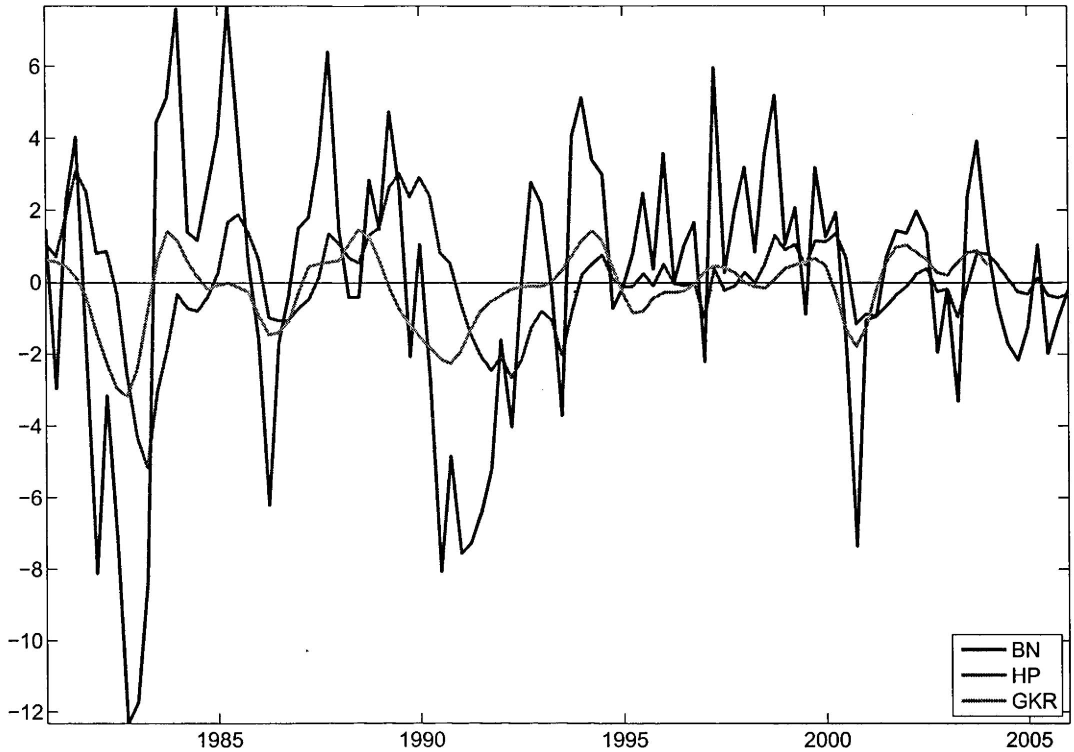
Table 5.4: SRVAR variance decomposition of output, interest, inflation and real exchange rate using BN decomposition

Horizon	Foreign interest	Foreign output	Foreign inflation	Output	Interest	Cost push	exchange rate	TOT
				Output				
1	49.1	0.0	1.5	5.2	0.2	0.7	7.4	35.9
4	41.7	17.1	1.8	4.4	0.5	5.2	4.8	24.5
8	40.5	17.0	1.9	4.4	0.5	6.6	4.8	24.3
12	40.1	16.7	1.9	4.3	0.5	7.2	4.8	24.6
50	39.4	16.6	2.0	4.4	0.5	7.5	5.0	24.6
				Interest rate				
1	2.4	2.2	5.6	11.1	3.1	6.6	59.4	9.5
4	1.8	3.7	3.6	8.1	1.4	13.7	46.4	21.2
8	1.6	20.3	1.9	7.3	1.4	10.3	34.4	22.6
12	1.3	32.5	1.5	7.2	1.4	8.0	28.9	19.2
50	1.1	54.7	1.6	5.2	1.0	5.5	18.6	12.3
				Inflation				
1	25.7	0.8	1.2	0.1	8.2	63.1	0.5	0.4
4	19.6	3.1	1.6	3.7	6.0	44.2	19.8	2.1
8	16.2	11.9	1.7	6.1	4.9	37.2	19.2	2.8
12	14.1	21.4	1.5	6.5	4.3	32.3	17.5	2.5
50	10.8	38.9	1.8	5.1	3.3	24.6	13.2	2.3
				Exchange rate				
1	0.5	2.2	23.3	43.9	2.7	1.0	26.2	0.1
4	8.6	3.2	18.9	27.6	3.2	6.1	30.2	2.3
8	13.2	11.9	12.7	20.2	4.0	12.6	21.1	4.4
12	13.5	25.8	8.8	13.8	3.5	14.0	14.3	6.3
50	10.7	40.0	7.8	9.4	2.5	11.9	10.1	7.5

Table 5.5: SRVAR variance decomposition of output, interest, inflation and real exchange rate using HP filter

Horizon	Foreign interest	Foreign output	Foreign inflation	Output	Interest	Cost push	exchange rate	TOT
				Output				
4	17.5	30.8	0.7	8.7	0.2	0.1	12.1	30.0
8	17.7	29.0	1.9	8.4	0.3	0.5	13.2	29.1
12	17.4	28.6	2.2	8.7	0.3	1.0	12.9	28.9
50	17.2	28.3	2.4	8.9	0.3	1.2	12.8	28.8
				Interest rate				
1	0.3	11.0	6.6	2.3	8.2	12.4	57.9	1.3
4	2.1	21.7	18.5	2.1	1.7	13.0	34.6	6.3
8	1.6	17.5	13.4	3.3	2.6	12.4	37.1	12.1
12	1.9	15.3	16.3	4.2	2.6	11.1	35.5	13.1
50	1.8	13.5	28.1	3.8	2.2	9.5	29.9	11.2
				Inflation				
1	24.9	0.1	0.5	0.1	56.4	2.9	11.4	3.7
4	18.8	0.5	1.5	3.2	38.1	3.3	28.0	6.5
8	16.4	0.6	1.9	6.8	32.3	3.4	29.5	9.0
12	15.7	0.6	4.7	7.2	30.7	3.3	29.1	8.8
50	14.7	1.7	10.1	6.7	28.3	3.2	26.8	8.5
				Exchange rate				
1	21.8	9.3	3.5	2.0	0.0	7.6	52.3	3.6
4	8.7	5.4	12.9	1.2	1.0	9.1	45.9	15.8
8	8.7	12.4	13.6	1.3	1.5	9.0	35.9	17.6
12	9.6	19.4	12.1	1.5	1.6	8.1	31.0	16.7
50	9.9	23.0	11.6	1.6	1.5	7.5	28.9	15.9

Figure 5.1: Cycles in Australian GDP



Note: GKR is the cycle derived by Gillitzer, Kearns and Richards (2005) using a factor model.

Figure 5.2: Structural model IRF of technology, monetary policy, cost push, risk premium shock.

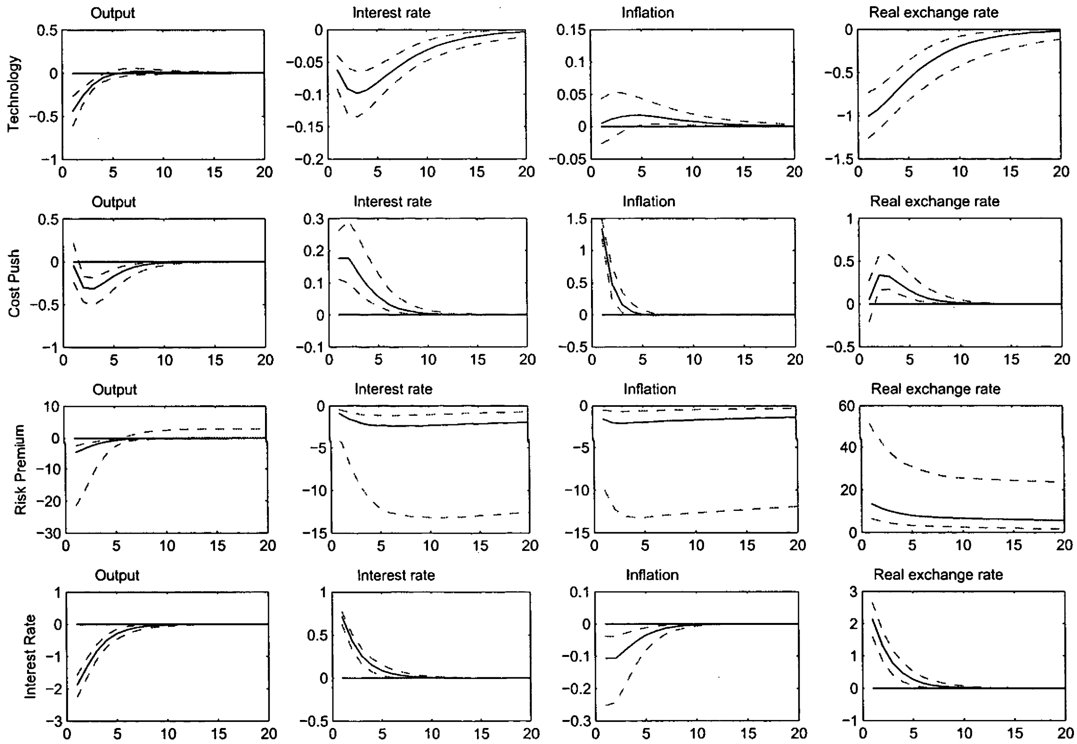


Figure 5.3: Structural model IRF of TOT, foreign interest, inflation and output shock.

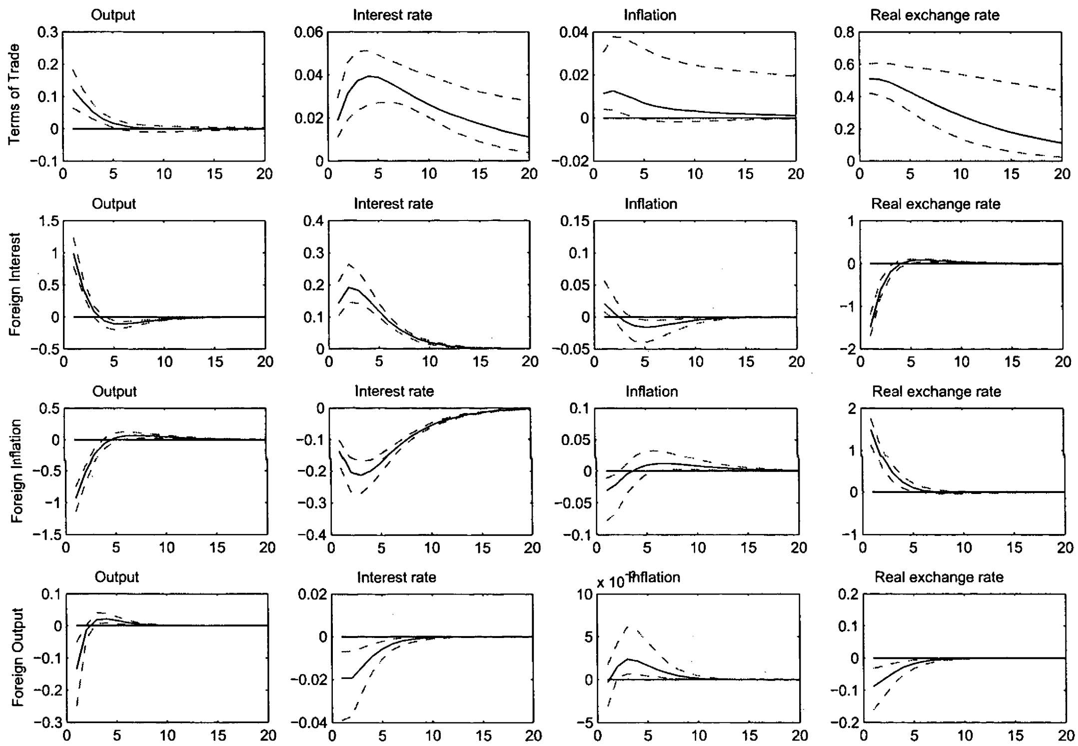
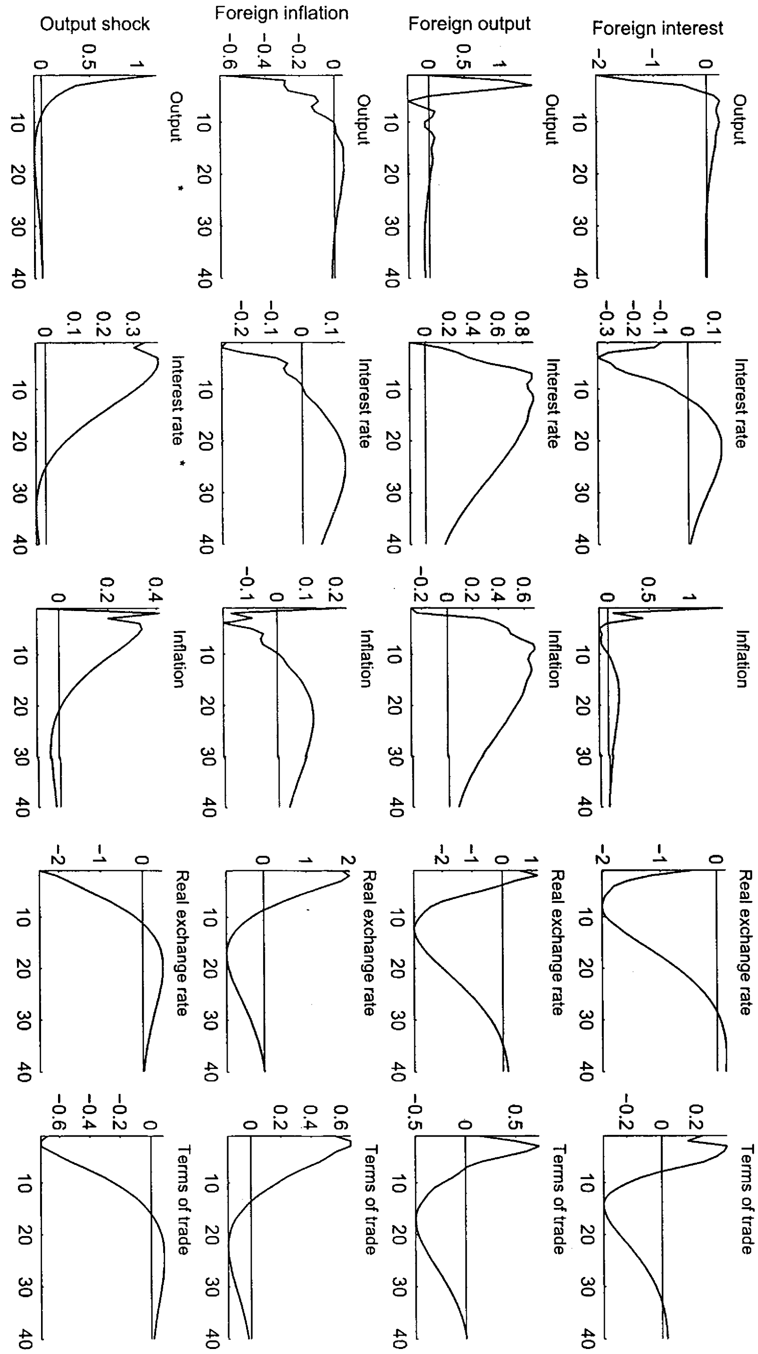
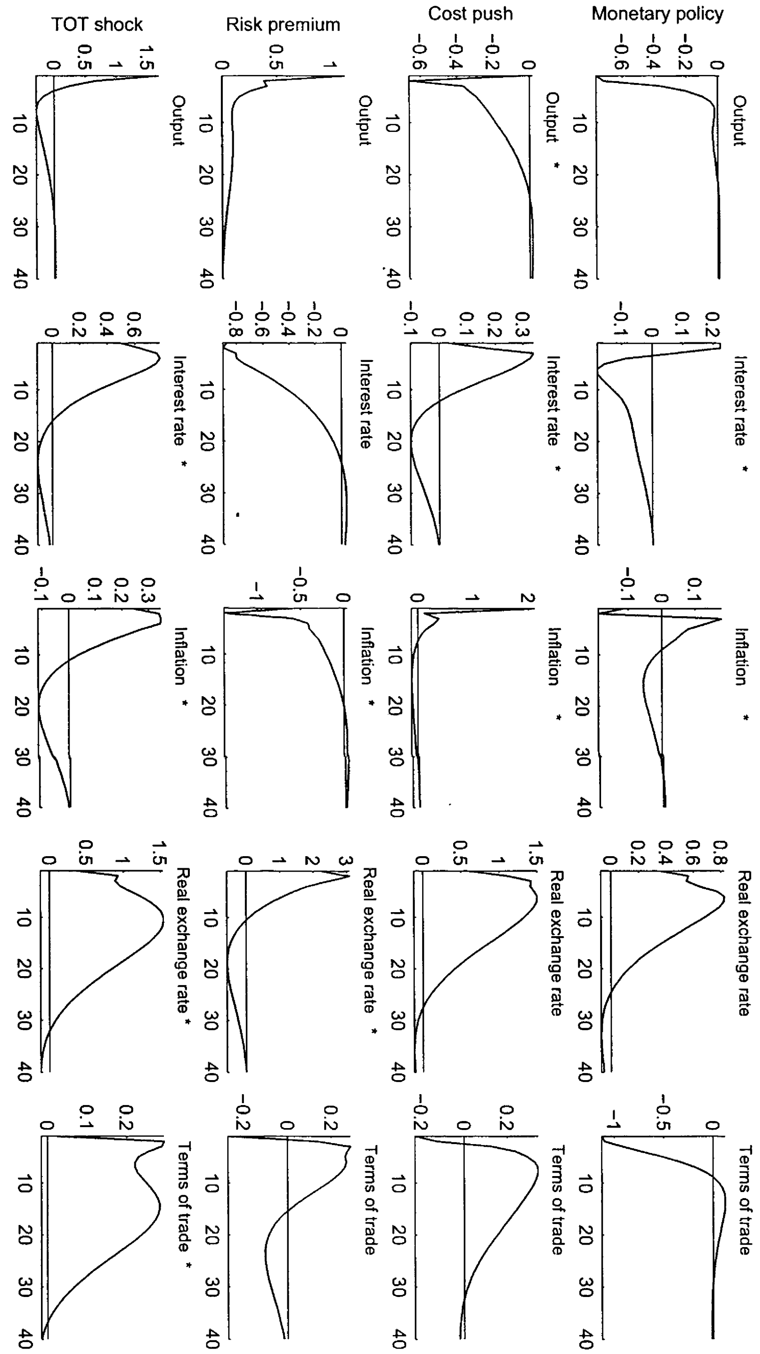


Figure 5.4: SRVAR IRF of foreign output, interest, inflation and domestic output shock.



Note: * indicate impulse responses where sign restrictions are imposed.

Figure 5.5: SRVAR IRF of monetary policy, cost push, risk premium and TOT shock.



Note: * indicate impulse responses where sign restrictions are imposed.

Figure 5.6: SRVAR variance decomposition of foreign vs domestic factors Across 2000 Rotations.

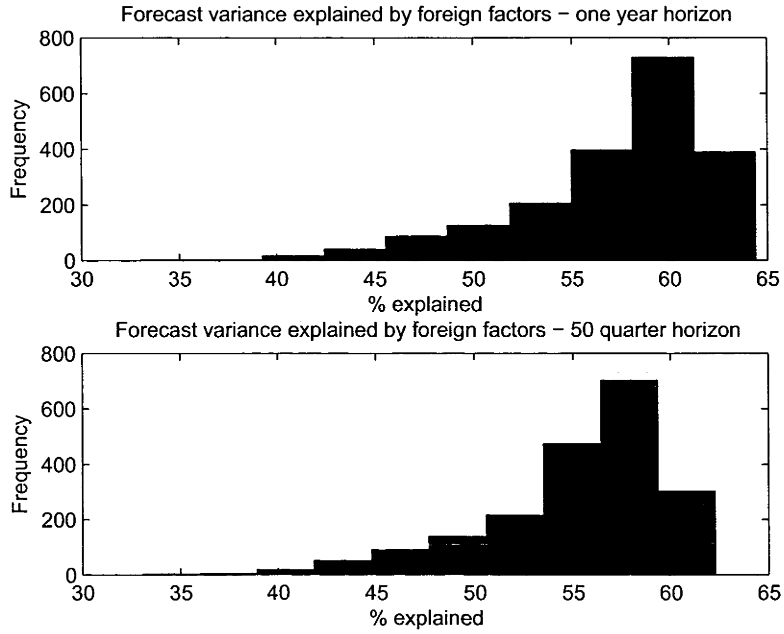
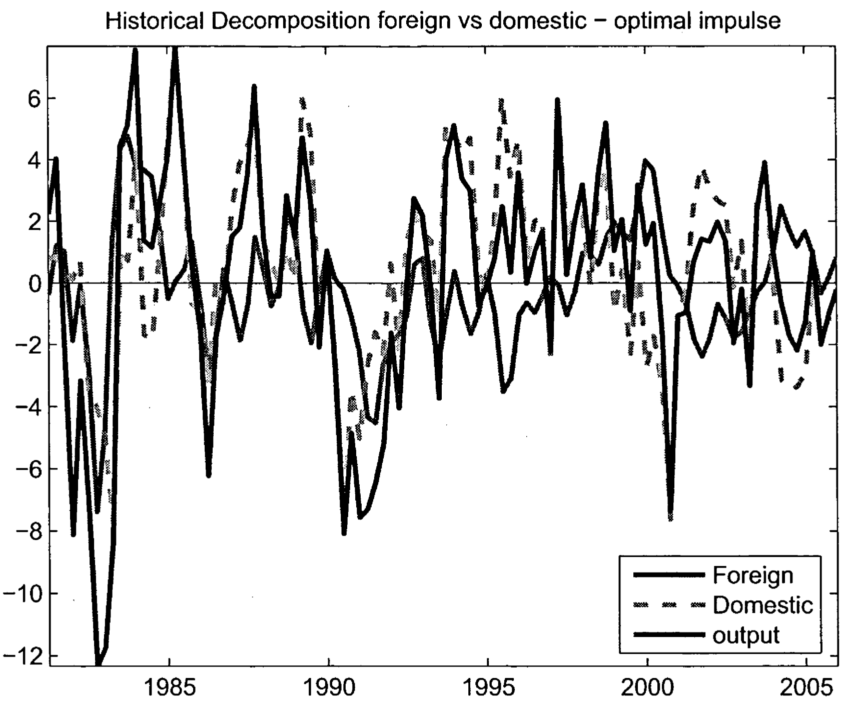


Figure 5.7: Historical decomposition of output using US data.



5.A Appendix

5.A.1 Sign restriction algorithm

Define an $(n \times n)$ orthonormal rotation matrix Q such that:

$$Q = \prod_{i=1}^{n-1} \prod_{j=i+1}^{n} Q_{i,j}(\theta_{i,j}) \tag{5.14}$$

$$\text{where} \quad Q_{i,j}(\theta_{i,j}) = \begin{array}{cc} & \begin{array}{ccccccc} & & \text{col } i & & \text{col } j & & \\ & & \downarrow & & \downarrow & & \end{array} \\ \begin{array}{c} \\ \\ \text{row } i \rightarrow \\ \\ \text{row } j \rightarrow \\ \\ \\ \end{array} & \begin{bmatrix} 1 & & & & & & \\ & \cdots & & & & & \\ & & \cos(\theta_{i,j}) & \cdots & -\sin(\theta_{i,j}) & & \\ & & \cdots & 1 & \cdots & & \\ & & \sin(\theta_{i,j}) & \cdots & \cos(\theta_{i,j}) & & \\ & & & & & \cdots & \\ & & & & & & 1 \end{bmatrix} \end{array}$$

where $\theta_{i,j} \in [\ 0, \pi\ ]$. This provides a way of systematically exploring the space of all VMA representations by searching over the range of values of $\theta_{i,j}$. While Canova and De Nicolo (2002) propose setting a up grid over the range of values for $\theta_{i,j}$, the following algorithm generates the Q's randomly from a uniform distribution:

1. Estimate the VAR in Equation (5.10) using OLS to obtain the reduced form variance covariance matrix V and compute $\tilde{V}$;

2. Compute the Choleski decomposition of $\tilde{V_{11}}$ and $\tilde{V_{22}}$, where $H_{11} = chol(\tilde{V_{11}})$ and $H_{22} = chol(\tilde{V_{22}})$;

3. For both the foreign and domestic block, draw a vector of $\theta_{i,j}$ from a Uniform $[\ 0, \pi\ ]$ distribution;

4. Calculate $Q = \prod_{i=1}^{n-1} \prod_{j=i+1}^{n} Q_{i,j}(\theta_{i,j})$;

5. Use the candidate rotation matrix Q to compute $\epsilon_t = HQe_t$ and its corresponding structural IRFs $C(L)$ for domestic and foreign shocks;

6. Check whether the IRFs satisfy all the sign restrictions described in Table (5.2). If so keep the draw, if not, drop the draw;

7. Repeat (3)–(6) until 2000 draws, satisfying the restrictions, are found.

CHAPTER **6**

INTERNATIONAL TRANSMISSION OF SHOCKS: A TIME-VARYING FACTOR AUGMENTED VAR APPROACH TO THE OPEN ECONOMY

Abstract *

This paper extends the open economy FAVAR models with time-varying coefficients and stochastic volatility to examine possible changes to the transmission of foreign money supply, demand and supply shocks to the U.K. The proposed model captures the changing co-movements among the macroeconomic time series by allowing their dependence on common factors to evolve over time. It also allows for stochastic volatility in the innovation process of the factors. The main results are as follows: A foreign monetary policy easing has substantially different effects on the U.K. in the period after 1990. In particular, the response of the domestic economy in the period before 1990 resembles a classic beggar-thy-neighbor scenario, with increases in foreign money supply resulting in a fall in U.K. real activity. In the later period, the response is positive but insignificant. Our estimates attribute this change to a fall in exchange rate pass-through to domestic relative prices. A foreign aggregate demand shock had a large positive impact on U.K. GDP during the years 1980-1990, but its impact in the more recent period has been substantially smaller. Foreign supply shocks were important for U.K. inflation during the 1970s and the persistence of the inflation response has also been smaller since the early 1980s.

*Chapter (6) is a summary of joint work with Haroon Mumtaz (Bank of England).

6.1 Introduction

UNDERSTANDING OF the international transmission mechanism of economic shocks is an important step towards identifying the best policy response in an individual economy to international developments. In a world economy, which has experienced a steady increase in integration across goods, capital and financial markets, the international aspect of the transmission mechanism has become an essential ingredient in policy discussions.

An important empirical regularity observed since the mid-1980s, is the substantial decline in the volatility of output and inflation across OECD countries, a phenomenon known as the "great moderation". In addition, over the same period the level and persistence of inflation has remained at historical lows. Many studies have documented reduced form evidence in support of this observation. For example Kim and Nelson (1999), McConnell and Perez-Quiros (2000), and Cogley and Sargent (2005) in the case of the U.S. and Benati (2006) for the U.K. However, the issues related to causes and consequences of these changes have been more controversial. A large literature has examined changes to the monetary transmission mechanism during the great moderation, and conclusions are mixed. Cogley and Sargent (2002), and Clarida et al. (2000) lend support to the hypothesis that changes in the U.S. macroeconomic dynamics were linked to the change in macroeconomic stabilization policies. On the other hand, Primiceri (2005), Sims and Zha (2006), and Gambetti et al. (2008) are more sympathetic to the idea that it is the absence of adverse non-policy shocks that has contributed to the great moderation. The literature so far has largely ignored the possible effects of changes in the international transmission mechanism over the great moderation period. This paper focuses on this issue.

A large empirical literature has investigated the international transmission of monetary and non-monetary shocks using small scale structural Vector Auto-Regression (SVAR) models. The identification restrictions in these models are often a controversial topic, where different identifying assumptions can lead to quite different conclusions. Several recent papers have proposed alternative identification structures including, amongst others, the recursive schemes in Grilli and Roubini (1995), Eichenbaum and Evans (1995), Dungey and Pagan (2000), and Faust and Rogers (2003), the non-recursive schemes in Cushman and Zha (1997), Kim and Roubini (2000), and Kim (2001), and the sign restrictions in Canova (2005), Scholl and Uhlig (2006), and Liu (2008).

Most of these contributions are based on VAR models with only a few selected variables. Arguably, central banks across the world monitor (and possibly respond to) a far wider information set than typically assumed in these small-scale VARs. To overcome this, Boivin and Giannoni (2008), and Mumtaz and Surico (2009) extend the Factor-Augmented VAR (FAVAR) model proposed by Bernanke et al. (2005) to the open economy setting. The FAVAR model helps address the limited information problem, in particular, they found many of the open economy anomalies disappeared when a large panel of data was used. However, a common assumption is that both the volatility of the stochastic driving process and the nature of co-movements among the variables have not changed over time.[1] As discussed earlier, many closed economy studies have shown significant decreases in output and inflation volatility, and documented changes to the transmission mechanism during the great moderation. Therefore, it is unsatisfactory to simply assume the size and the transmission of international shocks have not changed over this period.

This paper extends the open economy FAVAR models with time-varying coefficients and stochastic volatility to examine possible changes to the international transmission mechanism of shocks. The proposed model captures the changing co-movements among macroeconomic time series by allowing their dependence on common factors to evolve over time. It also allows for stochastic volatility in the innovation process of the factors. We treat the U.K. as a small open economy and take an agnostic approach in modeling its interactions with the rest of the world.

The main contribution of the paper is to assess possible changes to the transmission of world monetary policy, demand and supply shocks to the U.K. economy. A further advantage of our approach is that it allows us to derive the dynamic responses for a wider range of economic indicators without placing overly restrictive prior restrictions on the model's parameters.

The main results of the paper are as follows: A foreign monetary policy easing has substantially different effects on the U.K. in the period after 1990 compared to the period 1980-1990. In particular, the response of the domestic economy in the period before 1990 resembles a classic beggar-thy-neighbor scenario, with increases in foreign money supply resulting in a fall in U.K. real activity. In contrast, the post-1990 period is characterized with positive but insignificant response of U.K. real activity to a rise in foreign money supply. Our estimates attribute this to a fall in the degree of exchange rate pass-through to

[1] Boivin and Giannoni (2008) estimate their model over two sub-periods by introducing a dummy variable.

relative prices. A foreign aggregate demand shock had a large positive impact on U.K. GDP during the years 1980-1990. Its impact over the more recent period has been substantially smaller. Foreign supply shocks were important for U.K. inflation during the 1970s. The persistence of the inflation response has been smaller since the early 1980s.

The paper is organized as follows. Section (6.2) outlines the empirical model and discusses the identification assumptions. Section (6.3) explains the estimation procedure and the data used for the investigation. Section (6.4) reports the co-movement of the international factors, dynamic effects of an unexpected fall in world interest rates, an unexpected increase in world activities and an unanticipated negative world supply shock on a selected subset of U.K. macroeconomic indicators. Section (6.5) contains concluding remarks and directions for future research.

6.2 An open economy FAVAR model with time-varying coefficients

6.2.1 The empirical model

The model consists of two blocks, one for the U.K. and the other for the rest of the world, which is ordered first.[2] The information about the U.K. and the rest of the world are summarized by K unobserved factors, $F_t = [F_t^* \ F_t^{UK}]'$, where $*$ denotes the foreign economies and UK denotes the domestic economy. The U.K. short-term interest rate, R_t, is the only observable factor. This together with the unobserved common components form the dynamic system that evolves according to the following transition equation:

$$\begin{pmatrix} F_t^* \\ F_t^{UK} \\ R_t \end{pmatrix} = \begin{bmatrix} B_{11}(L) & 0 & 0 \\ B_{21}(L) & B_{22}(L) & B_{23}(L) \\ B_{31}(L) & B_{32}(L) & B_{33}(L) \end{bmatrix} \begin{pmatrix} F_{t-1}^* \\ F_{t-1}^{UK} \\ R_{t-1} \end{pmatrix} + u_t \tag{6.1}$$

where $B(L)$ is a conformable lag polynomial of finite order p, and $u_t = \Omega_t^{1/2} e_t$ with the structural disturbances $e_t \sim N(0, I)$ and Ω_t is the stochastic co-variance of the reduced form shocks. The structure of $B(L)$ reflects the small open economy assumption such that the domestic factors do not impact on world factors, but not vice versa. The time-varying

[2]The term foreign and world are used inter-changeably.

covariance matrix of the VAR innovations, u_t, can be factored as

$$\mathrm{Var}(u_t) \equiv \Omega_t = A_t^{-1} H_t \left(A_t^{-1}\right)' \tag{6.2}$$

Following Primiceri (2005), the time-varying matrices H_t and A_t are defined as:

$$H_t = \begin{bmatrix} h_{1,t} & 0 & \cdots & 0 \\ 0 & h_{2,t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & h_{n,t} \end{bmatrix} \tag{6.3}$$

and

$$A_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \alpha_{21,t} & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{n1,t} & \cdots & \alpha_{nn-1,t} & 1 \end{bmatrix} \tag{6.4}$$

with $\ln h_{i,t}$, and the non-zero and non-unit elements of the matrix A_t is assumed to evolve as driftless random walks

$$\ln h_{i,t} = \ln h_{i,t-1} + \mu_{i,t}, \quad i = 1, \ldots, n \tag{6.5}$$

$$\alpha_{ij,t} = \alpha_{ij,t-1} + \xi_{ij,t}, \quad i = 2, \ldots, n \text{ and } j = 1, \ldots, n-1 \tag{6.6}$$

where the distributional assumptions regarding $[\mu_t, \ \xi_t]$ are stated below. The random walk assumption allows for permanent shifts in the stochastic volatility terms. Allowing the simultaneous relations (A_t) to vary over time is crucial for modeling the time varying dynamics of structural VAR models.

The unobserved factors are extracted from a large panel of N foreign and domestic indicators containing important information about the fundamentals of the economies. The factors are assumed to be related to the variables in the panel (X_t) according to the following observation equation:

$$\begin{aligned}
\begin{pmatrix} X_t^{Y^*} \\ X_t^{\pi^*} \\ X_t^{R^*} \\ X_t^{UK} \\ R_t \end{pmatrix} &= \begin{bmatrix} \Lambda_t^{Y^*} & 0 & 0 & 0 & 0 \\ 0 & \Lambda_t^{\pi^*} & 0 & 0 & 0 \\ 0 & 0 & \Lambda_t^{R^*} & 0 & 0 \\ 0 & 0 & 0 & \Lambda_t^{UK} & \Lambda_t^{R} \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} F_t^{Y^*} \\ F_t^{\pi^*} \\ F_t^{R^*} \\ F_t^{UK} \\ R_t \end{pmatrix} + v_t \qquad (6.7) \\
v_t &= \rho(L) v_t + \epsilon_t \qquad (6.8)
\end{aligned}$$

where $\Lambda_t^{Y^*}$, $\Lambda_t^{\pi^*}$ and $\Lambda_t^{R^*}$ are the factor loadings on foreign real activity, foreign inflation and foreign interest rates with size $N^{Y^*} \times 1$, $N^{\pi^*} \times 1$ and $N^{R^*} \times 1$ respectively; Λ_t^{UK} is $N^{UK} \times k$ matrix of factor loadings for the domestic unobserved factors and Λ_t^{R}, $N^{UK} \times 1$, captures the contemporaneous relationship between the domestic indicators and the short-term interest rate; and ϵ_t is a $(N-1) \times 1$ vector of i.i.d disturbances.[3]

Following Del Negro and Otrok (2008), the factor loadings $\Lambda_t^{Y^*}$, $\Lambda_t^{\pi^*}$, $\Lambda_t^{R^*}$, Λ_t^{UK} and Λ_t^{R} are also assumed to evolve as driftless random walks

$$\begin{aligned}
\Lambda_t^{Y^*} &= \Lambda_{t-1}^{Y^*} + \eta_t^{Y^*} \qquad (6.9) \\
\Lambda_t^{\pi^*} &= \Lambda_{t-1}^{\pi^*} + \eta_t^{\pi^*} \qquad (6.10) \\
\Lambda_t^{R^*} &= \Lambda_{t-1}^{R^*} + \eta_t^{R^*} \qquad (6.11) \\
\Lambda_t^{UK} &= \Lambda_{t-1}^{UK} + \eta_t^{UK} \qquad (6.12) \\
\Lambda_t^{R} &= \Lambda_{t-1}^{R} + \eta_t^{R} \qquad (6.13)
\end{aligned}$$

All the innovations in the model are assumed to be jointly normally distributed with the

[3] The last row of equation (6.7) is an identity which does not have an error term.

following assumptions on the variance covariance matrix:

$$V = \text{Var}\begin{pmatrix} \mu_t \\ \xi_t \\ \epsilon_t \\ \eta_t^{Y^*} \\ \eta_t^{\pi^*} \\ \eta_t^{R^*} \\ \eta_t^{UK} \\ \eta_t^{R} \end{pmatrix} = \begin{bmatrix} W & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & S & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Q & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & M^{Y^*} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & M^{\pi^*} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & M^{R^*} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & M^{UK} & M^{UK,R} \\ 0 & 0 & 0 & 0 & 0 & 0 & M^{UK,R} & M^{R} \end{bmatrix} \tag{6.14}$$

To reduce the number of estimated parameters, we further assume the covariance matrices for the stochastic volatility (W), the off-diagonal non-zero elements (S) and the idiosyncratic error terms in the observation equation (Q) are diagonal. However, we allow for correlations between the factor loadings in each equation but not across equations. In principle, one can allow for a much richer covariance structure among the innovations in the system. Nevertheless, there are at least two reasons in favor of the simplified structure described in (6.14). First, the high number of parameters in the system will require specifying sensible priors to prevent cases of ill-determined parameters. Second, as highlighted in Del Negro and Otrok (2008), a completely generic covariance structure will complicate the structural interpretation of the innovations.

The system (6.1)-(6.14) is the FAVAR model proposed by Bernanke et al. (2005) and extended to the open economy by Mumtaz and Surico (2009). The main innovation in this paper is the introduction of time-varying factor loadings and stochastic volatilities. This is important in order to examine changes to the international transmission mechanism.

6.2.2 Identification

6.2.2.1 Unobserved factors

There are three factors for the rest of the world representing international co-movements in real activity, inflation and short-term interest rates. The international factors are identified through the upper $(N^{Y^*} + N^{\pi^*} + N^{R^*}) \times 3$ block of the matrix in (6.7). We assume that all real activity series in the foreign block of the model share common dynamics and that such common dynamics are not shared by any other series in the panel. The international real activity factor is identified as the only factor that is loaded by all real activity series in the rest of the world. Similar restrictions are assumed for the international inflation and short-term interest rate factors.

The dynamics of the U.K. variables are captured by k U.K. factors, where k is assumed to be four. The U.K. factors are not identified in a sense that they are extracted from the full panel of U.K. series. The sub-matrix Λ_t^{UK} in (6.7) is a full matrix with the normalization assumption on the first k series. The reason for leaving the domestic factor loadings unrestricted is that the dynamics of the variables in X_t^{UK} will depend on the structure imposed on the loadings. For example, if all domestic activity series share a single domestic activity factor, then the response of all domestic activity indicators will also share the common dynamics up to a scale factor pinned down by the loading. One of the goals of this paper is to investigate any possible heterogeneity in the responses of domestic prices and activities across sectors, and therefore it is unsatisfactory to impose a tight constraint on the dynamics of the individual series. The vector Λ_t^R, measuring the contemporaneous relationship between the domestic indicators and the short-term interest rate is also left unrestricted.

The identification scheme described above imposes most of the structure on the foreign block while leaving the domestic block, whose responses are the object of investigation, relatively unconstrained. The dynamics of each domestic series is a linear combination of all U.K. factors and the domestic short-term interest rate. The transition equation (6.1) links the dynamic responses between the international and domestic factors. Together with the identification restrictions discussed in the next sub-section, the international factors serve to identify the foreign shocks.

6.2.2.2 Foreign shocks

We are interested in studying the dynamic effects of three shocks on the U.K. economy: an unanticipated fall in the interest rates in the rest of the world, an unanticipated expansion in international activity and a negative world supply shock.[4] The foreign shocks are identified using two schemes based on a mixture of sign and zero restrictions and a recursive scheme. The ordering of the FAVAR is $[\Delta Y_t^*,\ \pi_t^*,\ R_t^*,\ F_{j,t}^{UK},\ R_t]$ with $j = 1, \ldots, k$ and the letters denote international real activity growth, inflation and interest rates, domestic factors and domestic short-term interest rate, respectively.

In the recursive scheme, the impact matrix A_0 is assumed to be lower triangular and the

[4]The response of U.K to domestic shocks has been studied in Benati (2008).

block-zero structure for the lag polynomial matrix $B(L)$ implies that the rest of the world does not react to U.K. domestic conditions contemporaneously or with lags. This small open economy assumption is maintained across both identification schemes.

In our benchmark identification scheme, we impose a mixture of sign and zero restrictions:

$$\begin{pmatrix} u_{\Delta Y*} \\ u_{\Pi*} \\ u_{R*} \\ u_{F,uk} \\ u_R \end{pmatrix} = \begin{bmatrix} + & + & - & 0 & 0 \\ + & - & - & 0 & 0 \\ + & \times & + & 0 & 0 \\ \times & \times & \times & \times & \times \\ \times & \times & \times & \times & \times \end{bmatrix} \begin{pmatrix} e_{AD*} \\ e_{AS*} \\ e_{R*} \\ e_{F,uk} \\ e_R \end{pmatrix} \tag{6.15}$$

where e_t are the structural shocks and the sign restrictions are imposed as described in Appendix (6.A.1). In the foreign block, a shock to aggregate demand is associated, on impact, with an increase in world activity, inflation, and interest rates; a positive supply shock implies a fall in inflation and a rise in real activity, the interest rate response is left unrestricted; a positive shock to the short-term interest rate comes with a decline in real activity and inflation. Notice that the impact of international shocks on the domestic economy is left unrestricted.[5]

We check our results using an alternative identification scheme based on a Choleski decomposition. This implies the following contemporaneous restrictions:

$$\begin{pmatrix} u_{\Delta Y*} \\ u_{\Pi*} \\ u_{R*} \\ u_{F,uk} \\ u_R \end{pmatrix} = \begin{bmatrix} \times & 0 & 0 & 0 & 0 \\ \times & \times & 0 & 0 & 0 \\ \times & \times & \times & 0 & 0 \\ \times & \times & \times & \times & \times \\ \times & \times & \times & \times & \times \end{bmatrix} \begin{pmatrix} e_{\Delta Y*} \\ e_{\Pi*} \\ e_{R*} \\ e_{F,uk} \\ e_R \end{pmatrix} \tag{6.16}$$

Note that by placing the U.K. short term interest rate last, we implicitly identify a U.K. monetary policy shock under both schemes.

[5]A mixture of sign and zero restrictions is also used by Faust and Rogers (2003).

6.3 Estimation

6.3.1 Multi-step Gibbs sampling

The model in equations (6.1) to (6.14) is estimated using procedures described in Kim and Nelson (1998), Primiceri (2005) and Del Negro and Otrok (2008) to approximate the posterior distribution. Essentially, this amounts to reducing a complex problem of sampling from the joint posterior distribution into a sequence of tractable ones by sampling from the conditional distribution of a subset of parameters conditional on all other parameters of the model. The Multi-step Gibbs sampling procedure can be broken down into five main blocks.

6.3.1.1 Time invariant parameters

We initialize the factors using a simple principal component estimator. Given the values for the factors F_t, the time-varying factor loadings Λ_t, the stochastic volatilities H_t and the off-diagonal covariances A_t, we can then draw the time invariant parameters for the VAR coefficients $B(L)$, the autoregressive coefficients of the error term in observation equation $\rho(L)$ and the hyperparameter Q.

Drawing the VAR coefficients is complicated by the presence of heteroscedasticity in the VAR covariance. We derive the conditional posterior distribution of the VAR coefficients by re-writing the VAR as state-space system and the parameters are drawn using the algorithm described in Carter and Kohn (1994):

$$F_t = B_t(L)F_{t-1} + u_t \tag{6.17}$$

$$B_t(L) = B_{t-1}(L) \tag{6.18}$$

where $B_t(L)$ is assumed to be time-invariant and the covariance of u_t is Ω_t. Note that the restrictions implied by the small open economy assumption are incorporated by using an appropriate prior distribution for $B_t(L)$:

$$p\left(B(L)\right) \sim N\left(B_0, \Omega_0\right)$$

where B_0 has all elements equal to zero except those corresponding to the first lagged dependent variables which are set equal to the autocorrelation coefficient obtained via univariate autoregressions on the initial value of F_t. The values of Ω_0 are chosen such that they imply a very strong prior belief that the elements in the top block of $B(L)$ in equation (6.1) equal zero.

For the autoregressive coefficients ($\rho(L)$) of the error term in equation (6.8), the conditional posterior distribution is easy to derive. To keep the notation simple, we write down the case where $L = 1$. Conditional on the factors (F_t) and the factor loadings (Λ_t), the errors in the measurement equation are independent across each equation i. We can draw ρ from its conditional posterior distribution given Q

$$\rho|Q \sim N(\rho_1, \Sigma_1) \tag{6.19}$$

where $\rho_1 = (\Sigma_0^{-1} + Q^{-2}v_{t-1}'v_{t-1})^{-1}(\Sigma_0^{-1}\rho_0 + Q^{-2}v_{t-1}'v_t)$ and $\Sigma_1 = (\Sigma_0^{-1} + Q^{-2}v_{t-1}'v_{t-1})^{-1}$. We assume that the prior mean $\rho_0 = 0$ and the prior variance $\Sigma_0 = 1$. Given ρ, we then draw the hyperparameter Q from an inverse Gamma distribution $IG(\frac{a_1}{2}, \frac{\delta_1}{2})$, where $a_1 = a_0 + T$ and $\delta_1 = \delta_0 + (v_t - \rho v_{t-1})'(v_t - \rho v_{t-1})$.[6]

6.3.1.2 Unobserved factors

In the second block of the Gibbs sampling, we draw the factors conditional on all other parameters of the model. Rewriting the state and observation equation in (6.1) and (6.7) in compact form:

$$F_t = B_t(L)F_{t-1} + u_t \tag{6.20}$$

$$X_t = \Lambda_t F_t + v_t \tag{6.21}$$

Since v_t is assumed to be autocorrelated, we rewrite (6.21) as

$$(I - \rho(L))X_t = (I - \rho(L))(\Lambda_t F_t) + \epsilon_t \tag{6.22}$$

The measurement errors ϵ_t in (6.22) are now i.i.d $N(0, Q)$. Equations (6.20) and (6.22) give the standard Kalman filter system. We can now apply Carter and Kohn's (1994) procedure

[6] a_0 and δ_0 are the prior shape and scale parameter of the inverse Gamma distribution.

to the above system to calculate F_t. The distribution of the factors F_t is linear and Gaussian:

$$F_T|\Upsilon \sim N(F_{t|T}, V_{t|T}) \tag{6.23}$$

$$F_t|F_{t+1}, \Upsilon \sim N\left(F_{t|t+1,F_{t+1}}, V_{t|t+1,F_{t+1}}\right) \tag{6.24}$$

where Υ represent all other parameters in the model, $t = T-1, ..1$, and:

$$F_{T|T} = E(F_T|\Upsilon) \tag{6.25a}$$

$$V_{T|T} = Cov(F_T|\Upsilon) \tag{6.25b}$$

$$F_{t|t+1,F_{t+1}} = E(F_t|\Upsilon) \tag{6.25c}$$

$$V_{t|t+1,F_{t+1}} = Cov(F_t|\Upsilon) \tag{6.25d}$$

As shown by Carter and Kohn (1994) the simulation proceeds as follows. First we use the Kalman filter to draw $F_{T|T}$ and $V_{T|T}$ and then proceed backwards in time using:

$$F_{t|t+1} = F_{t|t} + V_{t|t}V_{t+1|t}^{-1}(F_{t+1} - F_t) \tag{6.26}$$

$$V_{t|t+1} = V_{t|t} - V_{t|t}V_{t+1|t}^{-1}V_{t|t} \tag{6.27}$$

6.3.1.3 Time-varying factor loadings

Conditional on the factors (F_t), the errors in the measurement equation are independent across i. This implies the innovations in equation (6.8) are also independent across i. Consequently, we can draw the time-varying factor loadings one equation at a time. We apply the same transformation to the measurement equation as before which gives

$$(I - \rho(L))X_t = (I - \rho(L))(\Lambda_t F_t) + \epsilon_t \tag{6.28}$$

$$\Lambda_t = \Lambda_{t-1} + \eta_t \tag{6.29}$$

where the variance of η_t is block diagonal, that is the factor loadings are independent across equations but correlated within the same equation. For the i^{th} equation $\eta_t^i \sim N(0, M^i)$. Using equation (6.28) together with the law of motion for Λ_t in (6.29) allows us to draw the time-varying factor loadings (Λ_t) using Carter and Kohn's (1994) algorithm from its conditional distribution $N(\Lambda_{t|T}^*, V_{t|T}^{\Lambda^*})$. The hyperparameters for the variance of η_t, M, are drawn from an inverse Wishart distribution.

Following Del Negro and Otrok (2008) we add an additional step in the sampler to estimate the initial condition Λ_0. Starting from a prior for $\Lambda_0 \sim N(\bar{\Lambda}_0, \bar{V}_0)$ obtained via OLS regressions on the pre-sample, we obtain the posterior estimate of Λ_0 by updating the mean and variance $\bar{\Lambda}_0$ and $\bar{V}_0$ using the methods described in Carter and Kohn (1994).

Given a draw for Λ_t, we then draw the hyperparameter M^i from an Inverse Wishart distribution with a scale parameter $\eta_t^{i\prime}\eta_t^i + \delta_0^{M^i}$ and degrees of freedom given by sample size. We set the prior scale parameter δ_0^M as 1×10^{-3}.

6.3.1.4 Time-varying simultaneous relations:

Given the factors (F_t), the VAR coefficients ($B(L)$) and stochastic volatility terms (H_t), we can draw the time-varying simultaneous relations (A_t). Let α_t be the vector of non-zero and non unit elements of the matrix A_t (stacked by rows). One can rewrite the VAR model in (6.1) as

$$A_t(F_t - B(L)F_t) = A_t\hat{F}_t = H_t e_t \tag{6.30}$$

Taking $B(L)$ as given, $\hat{F}_t$ is computable. Since A_t is a lower triangular matrix, (6.30) can be written as

$$\hat{F}_t = Z_t \alpha_t + H_t e_t \tag{6.31}$$

where Z_t is the following $n \times \frac{n(n-1)}{2}$ matrix

$$Z_t = \begin{bmatrix} 0 & \cdots & \cdots & 0 \\ -\hat{F}_{1,t} & 0 & \cdots & 0 \\ 0 & -\hat{F}_{[1,2],t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & -\hat{F}_{[1,\ldots,n-1],t} \end{bmatrix} \tag{6.32}$$

and $\hat{F}_{[1,\ldots,i],t}$ denotes the row vector of $[\hat{F}_{1,t}, \hat{F}_{2,t}, \ldots, \hat{F}_{i,t}]$. Intuitively, equation (6.31) is equivalent to regressing the error term of the VAR on other error terms according to the lower triangular structure. With the block diagonal assumption of S, this allows us to apply the standard state space method with stochastic volatility as described in Carter and Kohn (1994).

6.3.1.5 Stochastic volatility

Similarly, we can rewrite the VAR model in (6.1) as

$$A_t(F_t - B(L)F_t) = F_t^* = H_t e_t \tag{6.33}$$

Given $B(L)$ and A_t, F_t^* are observed. Notice the stochastic volatilities are mutually independent, this allows us to proceed on an equation-by-equation basis. We draw the stochastic volatility terms using the date-by-date blocking scheme as in Jacquier et al. (1994). Note that the scale of the factors is not identified a priori. As in Del Negro and Otrok (2008) we fix the initial value of H_t to normalize the scale of the factors.

We generate 20,000 Gibbs sampling replications as described above and discard the first 19,000 as burn-in. The posterior moments vary little over the retained draws providing evidence of convergence to its stationary distribution.

6.3.2 Generalized impulse response functions

Given the time-varying nature of the model, we follow Koop et al. (1996) in computing the generalized impulse response functions, Δ_t, defined as:

$$\Delta_t = E\left(Z_{t+s}|\Psi_{t+s}, \mu_i\right) - E\left(Z_{t+s}|\Psi_{t+s}\right) \tag{6.34}$$

where Ψ denotes all the parameters and hyperparameters of the FAVAR, Z_t is the vector of all endogenous variables and s is the horizon under consideration. Equation 6.34 states that the impulse response functions are calculated as the difference between two conditional expectations. The first term denotes a forecast of the endogenous variables conditioned on a shock μ_i. The second term is the baseline forecast, i.e.: conditioned on the scenario where the shock is equal to zero. The conditional expectations in 6.34 are computed via Monte Carlo integration for 500 replications for each Gibbs sampler. Details on the Monte Carlo integration procedure can be found in Koop et al. (1996).

6.3.3 Data description

We use quarterly data from 1974Q1 to 2005Q1. The data set spans 17 countries and 560 series. We refer to the U.K. as the "domestic" economy. The "foreign" countries are

Canada, United States, Germany, France, Italy, Belgium, Netherlands, Portugal, Spain, Finland, Luxembourg, Sweden, Finland, Norway, Australia, New Zealand and Japan. The foreign block includes most of the U.K. main trading partners and the major industrialized economies across the world.

For each "foreign" country, we collect data on real activity, inflation and interest rates. For real activity, we consider data on output growth, employment, consumption and investment. Inflation is measured on the basis of a variety of domestic price indices, wage growth and import prices. Short-term interest rates are collected for each country.

The data set for the U.K. is very similar in composition to that of the "foreign block". In particular, we have many different real activity indicators, inflation series including components of the retail price index, narrow and broad money and a set of asset prices that include house prices and the effective exchange rate. A more detailed describtion is provided in Appendix (6.A.2).

6.4 Empirical results

This section describes the empirical results of the time-varying open economy FAVAR developed in Section (6.2). We report estimates of the unobserved foreign factors, time-varying variance decompositions, and compute the dynamic effects of an unanticipated fall in world interest rates, an unanticipated expansion of international activity and an unanticipated negative world supply shock using the generalized impulse response functions described earlier.

It is interesting to note that with a large information set, the two identification schemes no longer produce significantly different results. However, the sign-restrictions tend to produce wider confidence intervals because of weaker restrictions placed on the model. Here, we focus the discussion of the results on the sign-restriction scheme.[7]

6.4.1 International co-movements

We extract three common components from the foreign block of the panel using the identification described in Section (6.2.2). All variables are standardized. Figure (6.1) plots the estimated factors for world real activity, inflation and nominal interest rates (blue is the

[7]The results for the recursive ordering are available upon request.

estimated factors from the Gibbs sampling and magenta is the principal component estimator). The narrowness of the confidence interval indicates that the factors are estimated quite precisely.

It is interesting to note the similarities between the Gibbs sampling procedure and the principal components estimator (PCE) for the real activity and inflation factors. For the interest rate factor, the PCE is much more persistent and the cyclical fluctuations are less volatile compared with the Gibbs sampling procedure. Nevertheless, the cyclical fluctuations between the two series are similar. One explanation for the difference is that the Gibbs sampling procedure takes into account the autocorrelation of the idiosyncratic components of each series, therefore it attributes less of the observed persistence to the common component.

Comparing our estimates with previous studies such as Kose et al. (2003), a few patterns are very similar. The industrialized world experienced, on average, four severe recessions over the sample period: the mid-1970's oil price shock; the early 1980's recession associated with the debt crisis, loose U.S fiscal policy and tight monetary policy to bring down inflation; the early 1990's downturn; and the downturn in 2001 following the burst of the "dotcom" bubble. The dates roughly match those identified in Kose et al. (2003). Interestingly, by using higher frequency observations (quarterly data rather than annual), we identified the early 1980's recession as a "double-dip" in economic activity whereas estimates from Kose et al. (2003) suggest a prolonged recession. Our estimates suggest the decline in world economic activity in the mid-1970's was the steepest out of the four recessions, but its recovery was very rapid. The trough of the early 1980's recession was less severe but the recovery was slower due to the high interest rates over that period. The magnitude and the speed of recovery between the early 1990's and 2001 recession was remarkably similar. In both cases, the fall in the interest rate had helped to speed up the recovery.

The decline in the measure of international inflation is consistent with the notion of global disinflation put forward by Rogoff (2003). Despite the steady increase in oil and commodity prices between 2003-2005, world inflation remained relatively stable. World interest rates peaked in the early 1980's, since then, it has declined significantly reaching historical lows in the very recent past.

6.4.2 An unanticipated fall in world interest rates

6.4.2.1 World factors

A shock to the world interest rate factor cannot be interpreted literally as a foreign policy shock as a "world policy maker"does not exists. However, a generalized fall in interest rates may represent a situation that requires central banks across the world to deviate from the path implied by the systematic component of their monetary policy. The global disinflation stance in the early 1980's and the recent experience of unprecedented low policy rates are examples of such events. Here, we interpret the unanticipated fall in interest rates across the world as a monetary policy shock that occurs, on average, in the foreign block.[8]

Figure (6.2) plots the dynamic effects of the world factors in response to an expansionary monetary shock. The size of the shock is normalized to be a 1% decrease in the world interest rate factor. The first column plots the median time-varying impulse response functions (IRFs) to the shock, while the second and third columns illustrate the responses in 1975 and 2004 together with the 90% confidence intervals (light blue band). The decline in world interest rates generates a statistically significant expansion in real world activity and inflation. More interestingly, once we control for the time-varying stochastic volatility the response of the world factors are very similar across time. The inflation response is slightly larger in the latter part of the sample but the difference is small. Based on these estimates, the impact of world monetary policy shocks on real activity and inflation has changed little over the sample period.

6.4.2.2 U.K. external indicators

The key to understanding the international transmission mechanism to foreign monetary shocks rest on the behavior of the exchange rate and the response of relative prices to the shock. Figure (6.3) plots the time-varying responses for the U.K. nominal effective exchange rate (NEER), terms of trade, trade balance, import and export prices. Throughout the sample, the exchange rate appreciates in response to higher capital inflows from a higher interest rate differential. Its response was weakest in the early 1990's around the time of the U.K.'s exit from the European Exchange Rate Mechanism (ERM). That period was considered to be quite extraordinary where higher interest rate differentials did not

[8]Unfortunately with a limited number of factors, we cannot distinguish the effects of policy shocks versus policies aimed at bringing down the levels of inflation.

result in significant inflows of foreign capital. Consistent with the evidence reported in Mumtaz and Surico (2009), we also find little evidence of delayed overshooting as suggested in Eichenbaum and Evans (1995), and Faust and Rogers (2003). The peak impact of the exchange rate response occurs within the first two quarters of the shock.

In the earlier part of the sample, the median import price response falls immediately following the exchange rate appreciation and then rises slowly as the exchange rate depreciates back to equilibrium. This is consistent with the notion of producer currency pricing (PCP) by foreign exporters. More recently, pass-through from the exchange rate appreciation is smaller with the median response closer to zero. This lends more support towards local currency pricing (LCP) and is consistent with recent papers that document a fall in exchange rate pass-through in the U.K. (see for example Campa and Goldberg (2006) and Mumtaz et al. (2006)). As a result of this shock, export prices increase and the U.K. terms of trade improve. The trade balance deteriorates in the early years in the sample–a response that is consistent with PCP and high exchange rate pass-through. In which case, domestic consumers substitute out of more expensive domestic goods into cheaper foreign imports - the classic expenditure switching effect. In more recent years, the response of the trade balance has been largely insignificant again suggesting a possible shift towards LCP. The expenditure switching effect is now smaller because import prices do not fall by as much.

6.4.2.3 U.K. real activity and inflation

Figure (6.4) plots the time-varying response of investment, GDP and consumption. One striking feature is the uniform switch in the sign of contemporaneous responses from negative to positive among the real activity indicators in the early 1990's. This change is consistent with the possibility discussed above of a shift from producer to local currency pricing and a fall in exchange rate pass-through. Under PCP, high exchange rate pass-through implies that domestic consumers may shift to relatively cheaper imports. If this expenditure switching effect dominates the positive income effect from the expansion in world money supply, then domestic real activity is adversely affected as appears to be the case in the early part of the sample. On the other hand, if imports are priced in local currency and exchange rate pass-through is low, then there is less incentive for consumers to switch to imports and the beggar-thy-neighbor effect is ameliorated. See Betts and Devereux (1999) for a more detailed explanation.[9]

Figure (6.5) plots the time-varying response of nominal wages, inflation measures based on CPI and GDP deflator. Both inflation measures are higher immediately following the shock and reach their peak in four quarters. The response of inflation measures is fairly constant across the sample period.

6.4.2.4 U.K. asset prices

Figure (6.6) plots the time-varying response of 90-day, and 10-year government bond yields, and the growth rate of house and equity (measured by the FTSE index) prices. There is a statistically significant fall in both the short and long term interest rates following the shock. The magnitude of the fall is larger in the 70's and 80's relative to the inflation targeting period. House prices fall at the beginning of the sample while there is a positive impact on equity prices. In the later sample, these effects are virtually zero. Based on these estimates, aggressive foreign monetary expansion between 2001 and 2005 has little effect on the U.K.'s house and equity prices. This suggests the recent rise in asset prices is attributed to other shocks.

6.4.2.5 Results from recursive identification scheme

Figure (6.7) plots the time-varying response for various U.K. variables using the recursive identification scheme (RIS) described in (6.16). The sign and shape of the dynamic responses are largely similar across the two identification schemes. However, there are some interesting differences. First, the magnitude of the NEER and terms of trade response was smaller in the RIS. For example, the terms of trade now peaks at 0.6% rather than 1.5% earlier. Second, the responses for wages and the inflation measures from the RIS now returns to equilibrium much faster, within the first five quarters of the shock. Third, the switch in the sign of domestic economic activity now happens in a much more gradual manner. Nevertheless, the timing of the switch is the same.

[9]We have also investigated the possibility of changes to the policy stance using Lubik and Schorfheide's (2005) model as an alternative explanation. However, changes to both foreign and domestic policy stance cannot explain the switch in the sign of domestic activities.

6.4.3 An unanticipated increase in international activity

This subsection discusses the impact from an unanticipated increase in international real activity. We normalize the shock to be one unit of the world real activity factor where the units of the world factors are transformed to match U.S. data.

6.4.3.1 World factors

Figure (6.8) plots the time-vary IRFs for the three world factors. Both world inflation and interest rates rise on impact. While the response for world inflation is roughly the same over time, the interest rate response is clearly stronger during the disinflation period in the early 1980's. Over the NICE decade – non-inflationary consistently expansionary – (beginning in the early 1990's), the magnitude of the interest rate response remained fairly constant.

6.4.3.2 U.K. external indicators

Figure (6.9) plots the time-varying response for the NEER, the terms of trade and the trade balance. The NEER and the terms of trade were virtually unaffected by the shock. On the other hand, there is a small but persistent increase in the trade balance from higher demand in the rest of the world. It is difficult to account for the relatively large response of the domestic economy (to be discussed below) via the usual trade and relative price linkages. This suggests there maybe other missing channels in the transmission of world demand shocks. Dungey and Pagan (2000), and Pesaran et al. (2009) suggest more explicit roles for financial linkages in modeling the international transmission mechanism.

6.4.3.3 Selected U.K. variables

Figure (6.10) plots the time-varying IRFs for a selected subset of U.K. variables. At the beginning and the end of the sample, the impact on domestic real activity is close to zero. However, for a large part of the sample (between 1980 and 1998) domestic activity actually increases in response to higher world demand albeit the impact is relatively short lived. The strongest impact is between 1980-1990. Both nominal wages and CPI inflation is significantly positive in the medium term. While there were substantial time variations in the world interest rate response, the peak response of the domestic short-term interest rate response was very similar across the sample.

6.4.4 An unanticipated negative world supply shock

This subsection discusses the impact from an unanticipated negative world supply shock. We interpret this as a common shock that affects the cost of production around the world, the sudden surge in oil prices in the mid-1970's is an example of such a shock. The shock is normalized to have unit impact on the world inflation factor.

6.4.4.1 World factors

Figure (6.11) plots the time-varying response of the three world factors. Inflation is higher while output is lower immediately following the shock. The similarities along the adjustment paths across time is quite striking. Around the time of the 1975 oil shock, world interest rates rise substantially to help offset the inflationary pressure resulting from the higher oil prices. In the 1980's, the interest rate response was largely negative. Since then, world interest rates generally increases in response to supply shocks and the magnitude is a bit smaller.

6.4.4.2 U.K. external indicators

Figure (6.12) plots the time-varying response for the NEER, the terms of trade and the trade balance. The response of the U.K.'s external indicators in the 1970's was quite different to the rest of the sample. There was an appreciation of the exchange rate, a fall in the trade balance and an improvement in the terms of trade. These effects are less prominent in the current period.

6.4.4.3 Selected U.K. variables

Figure (6.13) plots the time-varying response for a selected subset of U.K. variables. Apart from the initial period, the nominal wage response to the world supply shock was largely negative. CPI inflation on the other hand increases following the shock. That means real wage adjusts downward in response to negative supply shocks originating from the rest of the world. It is interesting to note that the speed and magnitude of pass-through from the supply shock to CPI inflation is much smaller in the latter part of the sample, possibly due to a better anchor of inflation expectations. U.K. GDP falls following the supply shock. However, the magnitude of this fall is smaller in the recent period.

6.5 Conclusions

This paper has studied the international transmission of structural shocks in an open economy FAVAR model applied to the U.K. Unlike previous contributions, we use data on 17 countries and 560 variables, covering prices, activity and monetary indicators, to model the interaction between the foreign and domestic blocks of the VAR. In addition, we allow the relationships embodied in this model to change over time – we incorporate time-varying coefficients and stochastic volatility within the FAVAR framework. This allows us to better identify changes to the UK's macroeconomic dynamics due to changes in the size of the shocks (stochastic volatility) versus changes in the underlying structure of the economy (time-varying coefficients).

A foreign monetary policy easing has substantially different effects on the U.K. in the period after 1990. In particular, the response of the domestic economy in the period before 1990 resembles a classic beggar-thy-neighbor scenario, with increases in foreign money supply resulting in a fall in U.K. real activity. In contrast, the post-1990 period is characterized with a positive but insignificant response of U.K. real activity to this shock. Our estimates attribute this to a fall in exchange rate pass-through to relative prices. A foreign aggregate demand shock had a large positive impact on U.K. GDP during the years 1980-1990. Its impact over the more recent period has been substantially smaller. Foreign supply shocks were important for U.K. inflation during the 1970s. The persistence of the inflation response has been smaller since the early 1980s.

We find it is difficult for the usual exchange rate and relative price movements (trade linkages) to account for the large impact of foreign demand and supply shocks on the domestic economy. This suggests there maybe other channels beyond the usual trade linkages in the transmission of international shocks. More work should be done in thinking about financial linkages and "confidence effects" in modeling the international transmission mechanism. The recent dislocation in financial markets and synchronized response of economic activities around the world further emphasize this view. Furthermore, we have identified a switch in the response of the domestic economy to relative monetary policy shocks around the same time as the change in the U.K.'s monetary policy framework in the early 1990's. The possibility of interactions between exchange rate pass-through and policy deserve closer attention.

Figure 6.1: Standardized foreign factors (light blue band is the 95% confidence intervals)

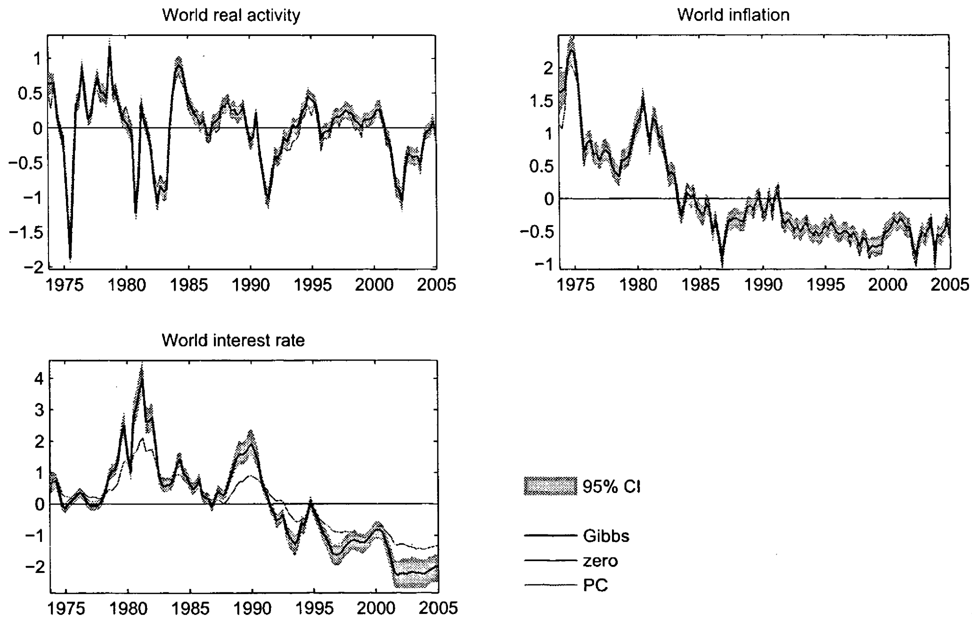


Figure 6.2: Response of world factors to a world monetary expansion

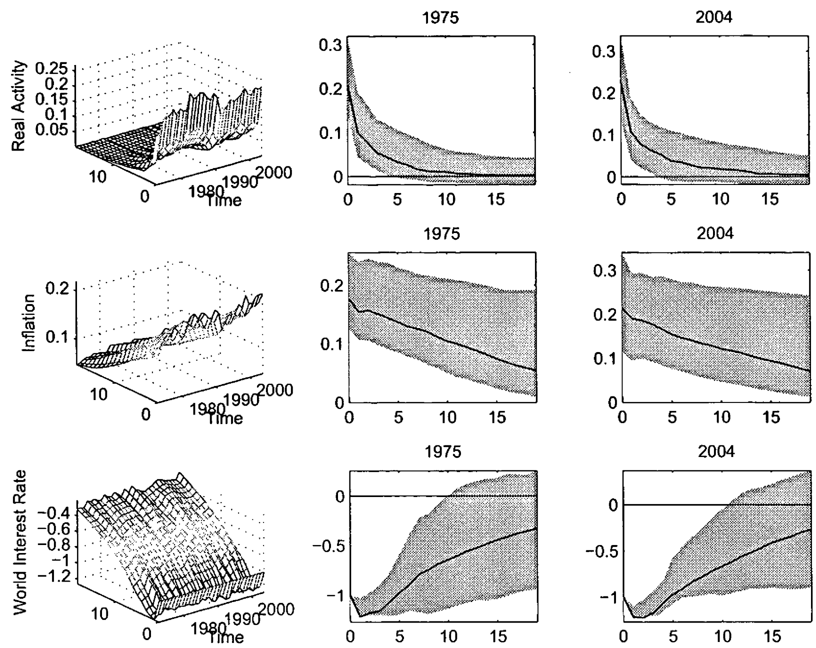


Figure 6.3: Response of U.K. external indicators to a world monetary expansion

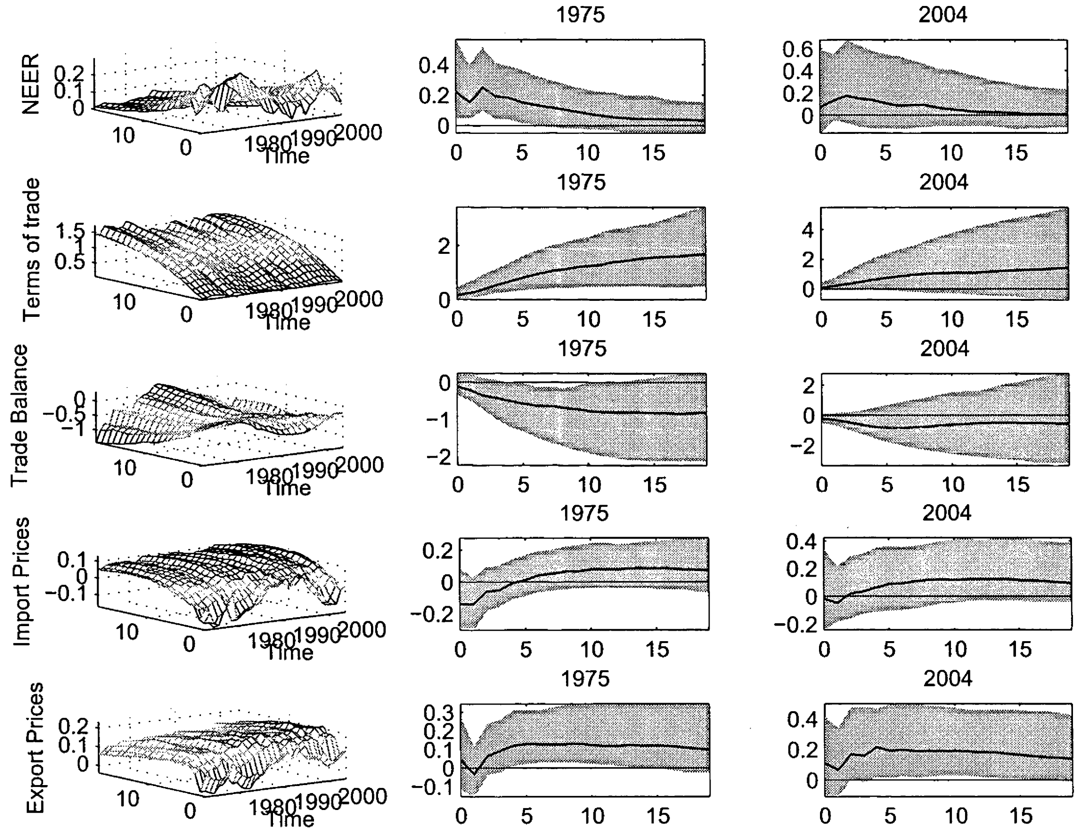


Figure 6.4: Response of U.K. real activity to a world monetary expansion

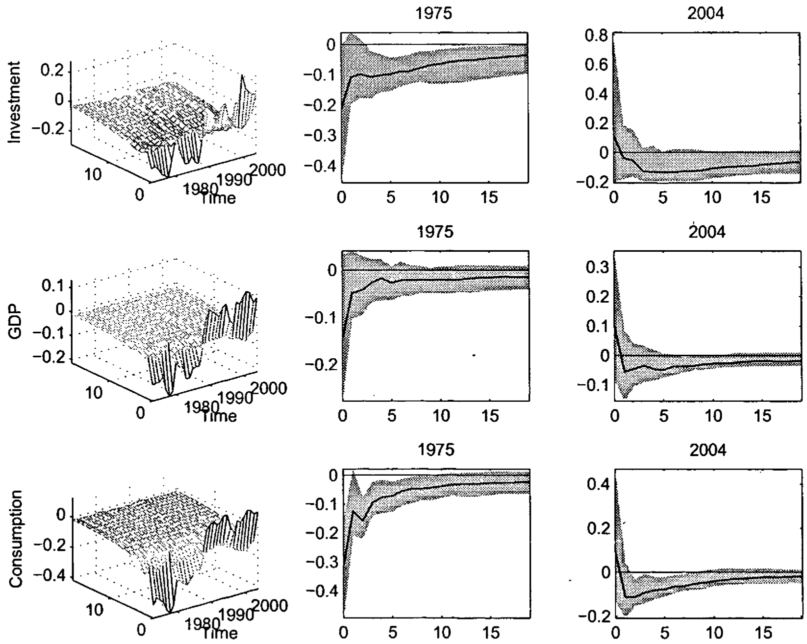


Figure 6.5: Response of U.K. inflation and wages to a world monetary expansion

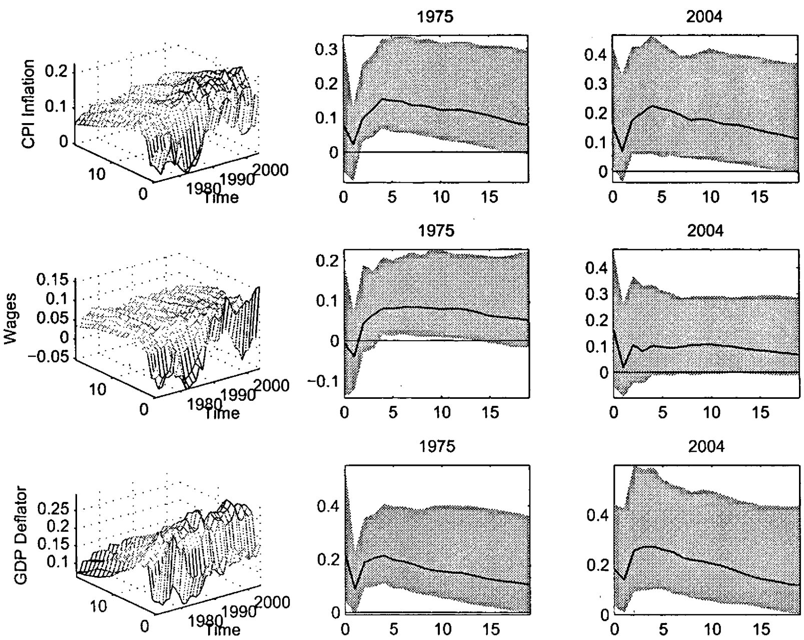


Figure 6.6: Response of U.K. asset prices to a world monetary expansion

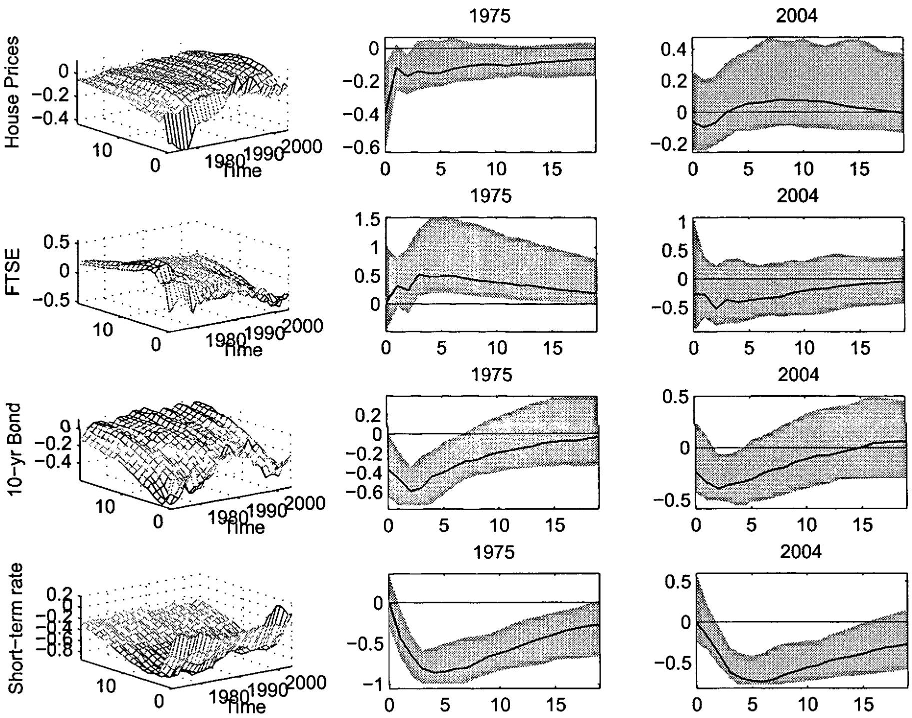


Figure 6.7: Response of U.K. variables to a world monetary expansion using recursive identification

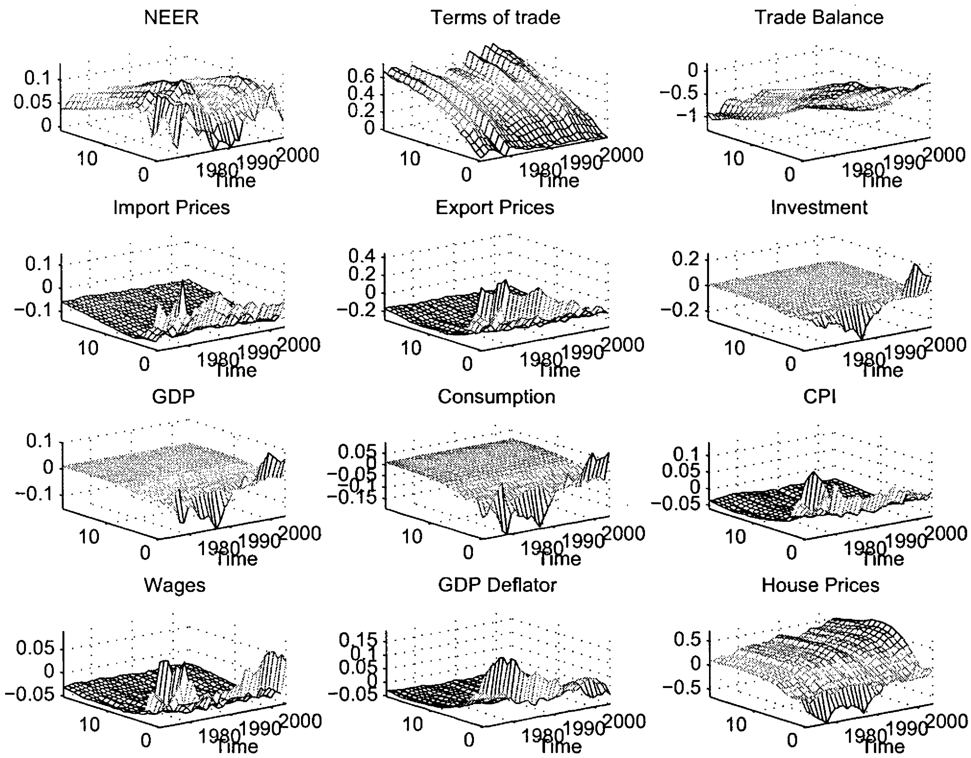


Figure 6.8: Response of the world factors to increases in international activities

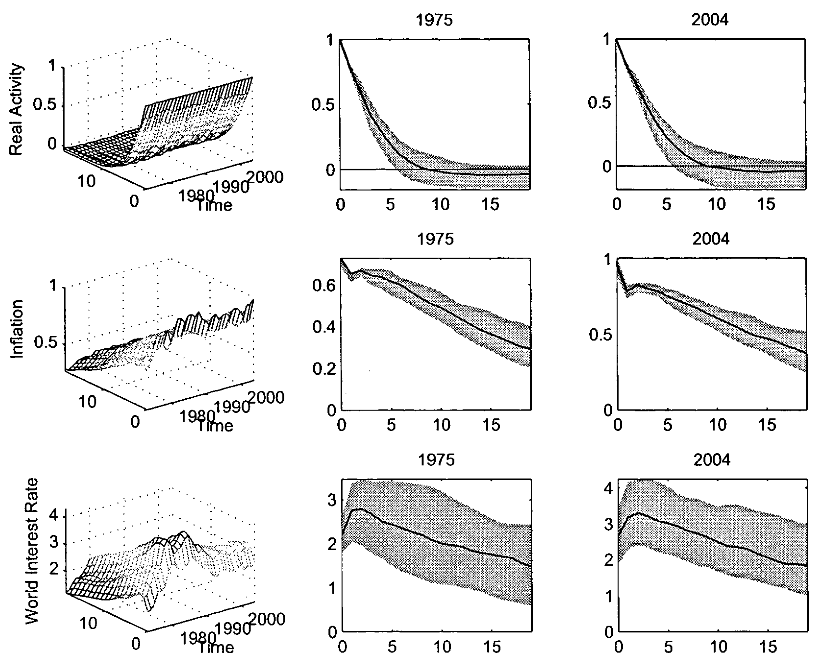


Figure 6.9: Response of U.K. external indicators to increases in international activity

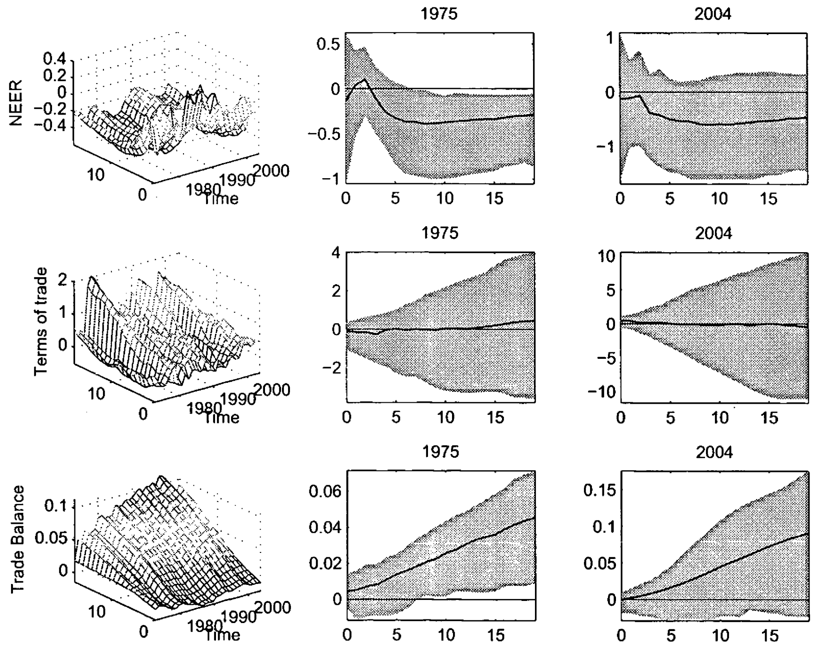


Figure 6.10: Response of selected U.K. variables to increases in international activities

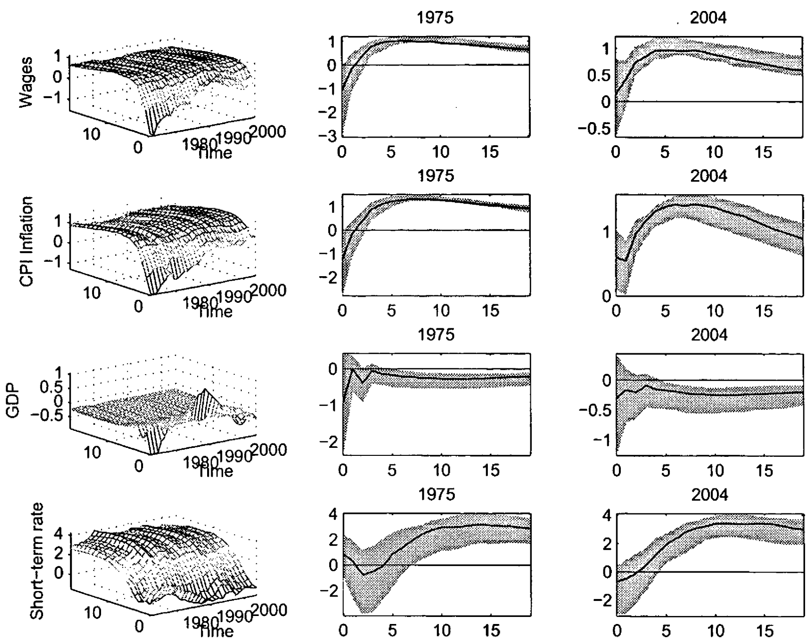


Figure 6.11: Response of the world factors to a negative world supply shock

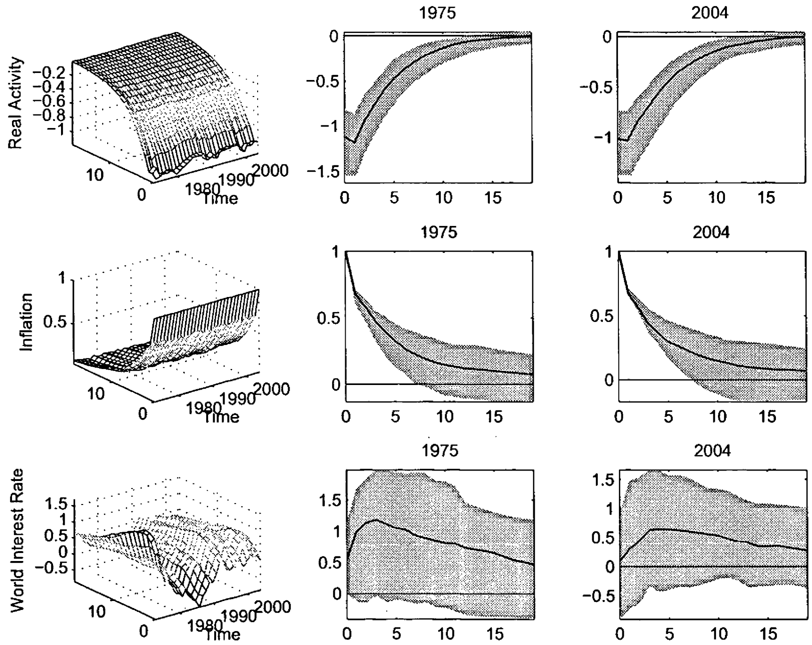


Figure 6.12: Response of U.K. external indicators to a negative world supply shock

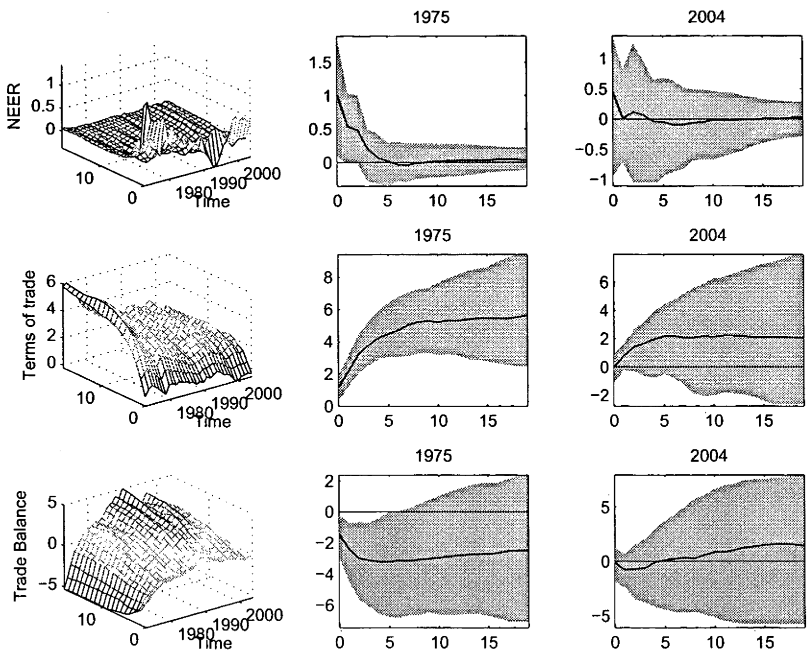
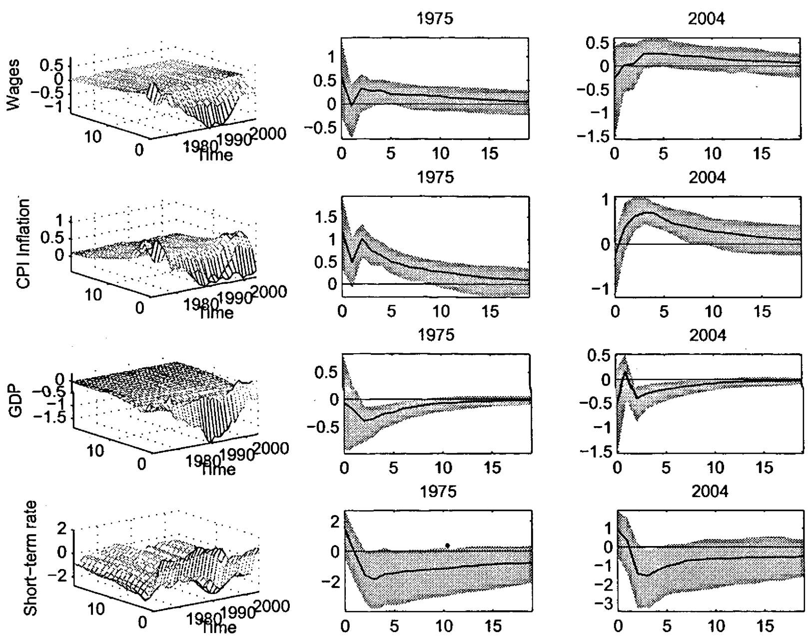


Figure 6.13: Response of selected U.K. variables to a negative world supply shock



6.A Appendix

6.A.1 Imposing the sign restrictions

The sign restrictions are imposed as follows. We compute the structural impact matrix, A_0, via a slightly modified version of the algorithm recently introduced by Rubio-Ramirez et al. (2006). Specifically, let $\Omega_t = P_t P_t'$ be the Choleski decomposition of the VAR covariance matrix Ω_t (with the foreign variables ordered before the U.K. variables), and let $\tilde{A}_{0,t} \equiv P_t$. We draw an $j \times j$ matrix, J, from the $N(0,1)$ distribution, where j denotes the dimension of "foreign" block in the VAR. We take the QR decomposition of J. That is, we compute the matrices Q and R such that $J = QR$.

This gives us a candidate structural impact matrix as $A_{0,t} = \tilde{A}_{0,t}\tilde{Q}$, where $\tilde{Q}$ is a $N \times N$ identity matrix with Q' in the top $j \times j$ block. Note that such candidate draw has a lower triangular structure for the U.K. block and, as in the standard Choleski decomposition, implies that U.K. shocks do not have a contemporaneous impact on the "foreign" block. If $A_{0,t}$ satisfies the sign restrictions, we keep it and move on to the next Gibbs sample. Otherwise, redraw J.

6.A.2 Description of the data

In the interest of brevity we do not provide an exact list of all 560 series in our panel. However this appendix gives an idea of the type of data used and the underlying sources. The full list is available on request from the authors.

6.A.2.1 International data

Our international data set contains data on real activity, inflation and interest rates for Canada, United States, Germany, France, Italy, Belgium, Netherlands, Portugal, Spain, Finland, Luxembourg, Sweden, Finland, Norway, Australia, New Zealand and Japan. All data series are seasonally adjusted. We take log differences of all series apart from interest rates. The data is then standardized.

Where available, our real activity data contains real GDP, industrial production, real household consumption expenditure, investment, exports, gross national income and unemployment. In terms of coverage, the US has the most detailed data with a breakdown of unemployment and production by sector. Most of the data is obtained from Datastream and

International financial statistics (IFS) database. The unemployment data is taken from the Global financial database and the US series are obtained from Federal Reserve Economic Data (FRED).

Our basic inflation data contains CPI, GDP deflator, measures of wage growth and import prices. Again, for the US we are also able to obtain a breakdown of CPI and PPI by sector. The series are obtained from Datastream and IFS.

The international interest rate data primarily contains short-term interest rates. These include discount rates, money market rates, treasury bill rates and central bank interest rates. The data is obtained from the Global financial database.

6.A.2.2 U.K. data

Similar to the international data, our data set on the U.K. contains data on real activity and inflation. We also include some indicator of money and key asset prices.

Real activity data includes real GDP, industrial production (with a broad sectoral break down), imports and exports, investment and real household consumption expenditure. The data set includes a very detailed sectoral breakdown of consumption quantities. The data is obtained from the Office of National Statistics (ONS).

Inflation data includes the main price indices (GDP deflator, CPI, RPI and RPIX) and components of the consumption deflator. ONS and the Bank of England are the main sources for the data.

Money data for the U.K. includes M0 and M4, with a sectoral breakdown of the latter. This data is obtained from the Bank of England.

The asset price data includes house prices, stock prices, exchange rates (pounds in terms of US dollars, Euros, Yen, Canadian and Australian Dollars) and the term structure of interest rates. The data are obtained from the Global financial database and the Bank of England.

CHAPTER 7

CONCLUSION

THE OVERALL goal of this thesis is to provide a deeper understanding of the role of monetary policy as a stabilization tool in a small open economy (SOE). International trade and financial market integration induce many additional constraints to the stabilization problem. This is a very broad topic with a large existing literature. The thesis contributes to this ongoing debate by presenting four case studies each looking at a self contained issue.

Chapter (3) looks at the importance of time-inconsistent policy for New Zealand and how this notion has led to a number of interesting insights regarding the central bank's behavior and institutional design. Chapter (4) uncovers the underlying macroeconomic stabilization objectives for three of the earliest inflation targeters: Australia, Canada and New Zealand. In particular, the role of exchange rate stabilization in the policy makers' objective function. Chapter (5) examines the sources of business cycle fluctuations focusing on the role of international shocks for Australia. Chapter (6) investigates changes to the international transmission mechanism in response to foreign disturbances for the U.K. The empirical analysis contained in this thesis is primarily focused on four SOEs – Australia, Canada, New Zealand and the United Kingdom. Although, the policy conclusions and methodologies developed here can be easily related or applied to other SOE studies.

7.1 Main results and policy implications

Chapter (3) develops an empirical model to investigate the degree of inefficiencies arising from discretionary policy relative to the commitment equilibrium. The discussion focused on analyzing the policy tradeoffs faced by the central bank within a SOE, and how that differs from a closed economy.

Two key results emerge from the analysis. First, the estimated size of the stabilization bias for a SOE is found to be nearly twice as large relative to that usually found in the closed economy counterpart. The result is robust across different loss function parameterizations and model parameters. As the economy becomes more open, the cost of discretionary policy relative to commitment equilibrium is higher. Second, the size of the stabilization bias increases with the policymaker's preference for stabilizing exchange rate fluctuations. This implies that a stronger attitude towards pre-commitment of policy will help minimize the inefficiency arising from the stabilization bias when the exchange rate is included as one of the stabilization objectives.

Chapter (4) estimates the macroeconomic policy objectives of the central banks of Australia, Canada and New Zealand within the context of a DSGE model. The parameter estimates reveal the objectives of these small open economy inflation targeters. The results emphasize the similarities rather than the differences in the macroeconomic objectives of the central banks of Australia, Canada and New Zealand.

Over the period considered, all three central banks show no concern for mitigating exchange rate volatility as an objective in its own right. However, all three central banks show a substantial concern for interest rate smoothing. The Reserve Bank of Australia shows the most desire to mitigate volatility in the output gap but in all three cases the estimated weight on the output gap is substantially lower than the weight on the deviation of annual inflation from target. Nevertheless, all central banks would be sensibly classified as flexible in their approach to inflation targeting. Another interesting outcome is that the resulting optimal policy rule still responds to exchange rate movements, even in the case where the central banks do not explicitly care about exchange rate stabilization.

The analysis has important implications for assessing the accountability and transparency of monetary policy. By jointly estimating the parameter estimates conditional on the same DSGE model, one can make inferences about objectives conditional on the environment each central bank operates under. Such joint estimates result in very different conclusions relative to uninformed inference based on the unconditional distributions of target variables such as annual inflation, the output gap, interest rates and the exchange rate.

Chapter (5) uses a small open economy VAR model to investigate the sources of business cycle fluctuations for the Australian economy. The VAR is identified using robust sign restrictions derived from an estimated small structural (DSGE) model rather than imposing zero-type restrictions. The results suggest that international factors account for over half the domestic output fluctuations while demand type shocks play a small role.

Chapter (6) studies the international transmission of structural shocks in an open economy FAVAR model applied to the U.K. Unlike previous contributions, the analysis uses data on 17 countries and 560 variables, covering prices, activity and monetary indicators, to model the interaction between the foreign and domestic blocks of the VAR. In addition, the relationships embodied in the model are allowed to change over time by incorporating time-varying coefficients and stochastic volatility within the FAVAR framework.

The results indicate a foreign monetary policy easing has substantially different effects on the U.K. in the period after 1990. In particular, the response of the domestic economy in the period before 1990 resembles a classic beggar-thy-neighbor scenario, with increases in foreign money supply resulting in a fall in U.K. real activity. In contrast, the post-1990 period is characterized with a positive but insignificant response of U.K. real activity to this shock. The estimates attribute this to a fall in exchange rate pass-through to relative prices. A foreign aggregate demand shock had a large positive impact on U.K. GDP during the years 1980-1990. Its impact over the more recent period has been substantially smaller. Foreign supply shocks were important for U.K. inflation during the 1970s. The persistence of the inflation response has been smaller since the early 1980s.

The conclusions drawn from Chapters (5) and (6) carry important implications for a small open economy central bank's stabilization policy. In addition to the usual domestic demand and supply shocks, policy makers should pay greater attention to disturbances originating from the rest of the world. In particular, the analysis has identified changes to the international transmission mechanism and this has important implications in terms of our understanding of the effects of foreign disturbances on the domestic economy.

7.2 Future research directions

The above findings and conclusions rest on quite a few important modeling assumptions. One common theme stressed throughout the thesis is the assumption with respect to trend and cycle decomposition. Even though the thesis takes a fairly agnostic view on which is the appropriate method and tests key conclusions against various different detrending methods, it is necessary for future research to shed more light on this contentious issue. One fruitful direction is to try and model the trend within the structural model's assumptions and estimate it with other parameters of the model.

Another potential area of research is to address the problem related to using mis-specified models for policy analysis. A famous quote by Box and Draper (1987) state that "*...all models are wrong; the practical question is how wrong do they have to be to not be useful.*", is very relevant to economic modeling. For example, the conclusions drawn in Chapter (3) rest on the assumption of Uncovered Interest Parity (UIP), despite the ongoing debate on whether UIP holds. It is important to assess the implication of using alternative assumptions on the model's predictions. Del Negro and Schorfheide (2005) have proposed using the DSGE-VAR methodology to assess the degree of potential mis-specification underlying the structural model. Another approach is to use Bayesian model averaging (using many mis-specified models) and robust policy to evaluate the robustness of the policy conclusions.

The analysis in Chapter (6) revealed that it was difficult for the usual exchange rate and relative price movements (trade linkages) to account for the large impact of foreign demand and supply shocks on the domestic economy. This suggest there maybe other channels beyond the usual trade linkages in the transmission of international shocks. More work should be done in thinking about financial linkages and "confidence effects" in modeling the international transmission mechanism. The recent dislocation in financial markets and synchronized response of economic activities around the world further emphasize this view.

Finally, Chapter (5) used sign restrictions from a DSGE model to help identify structural shocks in a VAR. Further work is needed to bring the two strands of macro-modeling methodologies, structural DSGE models and statistical VAR based models, closer together. Future research could therefore be directed towards using quantitative restrictions implied by a DSGE model for statistical VAR identification.

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